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(54) Title: CONSTITUTIVELY ACTIVATED SEROTONIN RECEPTORS (57) Abstract Mutations have been discovered in mammalian G protein-coupled serotonin 5-HT _{2A} and 5-HT _{2C} receptors which render the mutated receptors constitutively active. An alignment methodology based on the highly conserved sixth transmembrane domain has been discovered for the monoamine receptors which accurately predicts the amino acid position in the third intracellular loop which, when mutated, produces constitutive activation of the receptor. Constitutive activation of the G protein-coupled serotonin receptors has been shown by the demonstration of an enhanced affinity and potency for serotonin, by increased basal activity of the second messenger system in the absence of agonist, and by reduction of the basal second messenger activity by inverse agonists.		

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CONSTITUTIVELY ACTIVATED SEROTONIN RECEPTORS

The benefit of U.S. Provisional Application No. 60/039,465 filed February 27, 1997, and U.S. Provisional Application No. 60/061,268 filed October 7, 1997 is claimed for this application.

5 BACKGROUND OF THE INVENTION

Field Of The Invention

The present invention relates generally to the field of transmembrane receptors, more particularly to seven segment transmembrane G protein-coupled receptors, and most particularly to the serotonin (5-HT) receptors. Through
10 genetic mutational techniques, the amino acid sequences of the native 5-HT_{2A} and 5-HT_{2C} receptors have been modified so that the receptors exist in a constitutively activated state exhibiting both a greater response to agonists and a coupling to the G Protein second messenger system even in the absence of agonist. A method for constitutively activating G protein-coupled 5-HT receptors in general is
15 also disclosed.

Description Of Related Art

The research interest in G protein-coupled cell surface receptors has exploded in recent years as it has been apparent that variants of these receptors play a significant role in the etiology of many severe human diseases. These
20 receptors serve a diverse array of signalling pathways in a wide variety of cells and tissue types. Indeed, over the past 20 years, G protein-coupled receptors have proven to be excellent therapeutic targets with the development of several hundred drugs directed towards activating or deactivating them.

G protein-coupled receptors form a superfamily of receptors which are
25 related both in their structure and their function. Structurally the receptors are large macromolecular proteins embedded in and spanning the cell membrane of the receiving cell and are distinguished by a common structural motif. All the receptors have seven domains of between 22 to 24 hydrophobic amino acids forming seven α helixes arranged in a bundle which span the cell membrane
30 substantially perpendicular to the cell membrane. The transmembrane helixes are joined by chains of hydrophilic amino acids. The amino terminal and three connecting chains extend into the extracellular environment while the carboxy

terminal and three connecting chains extend into the intracellular environment. Signalling molecules are believed to be recognized by the parts of the receptor which span the membrane or lie on or above the extracellular surface of the cell membrane. The third intracellular loop joining helixes five and six is thought to be the most crucial domain involved in receptor/G protein coupling and responsible for the receptor selectivity for specific types of G proteins.

Functionally, all the receptors transmit the signal of an externally bound signalling molecule across the cell membrane to activate a heterotrimeric transducing protein which binds GDP (guanosine diphosphate). Upon activation, the bound GDP is converted to GTP (guanosine triphosphate). The activated G protein complex then triggers further intracellular biochemical activity. Different G proteins mediate different intracellular activities through various second messenger systems including, for example, 3'5'-cyclic AMP (cAMP), 3'5'-cyclic GMP (cGMP), 1,2-diacylglycerol, inositol 1,4,5-triphosphate, and Ca^{2+} . Within the human genome, several hundred G protein-coupled receptors have been identified and endogenous ligands are known for approximately 100 of the group. While the seven transmembrane motif is common among the known receptors, the amino acid sequences vary considerably, with the most conserved regions consisting of the transmembrane helixes.

Binding of a signalling molecule to a G protein-coupled receptor is believed to alter the conformation of the receptor, and it is this conformational change which is thought responsible for the activation of the G protein. Accordingly, G protein-coupled receptors are thought to exist in the cell membrane in equilibrium between two states or conformations: an "inactive" state and an "active" state.

In the "inactive" state (conformation) the receptor is unable to link to the intracellular transduction pathway and no biological response is produced. In the altered conformation, or "active" state, the receptor is able to link to the intracellular pathway to produce a biological response. Signalling molecules specific to the receptor are believed to produce a biological response by stabilizing the receptor in the active state.

Discoveries over the past several years have shown that G protein-coupled receptors can also be stabilized in the active conformation by means other than

binding with the appropriate signal molecule. Four principal methods have been identified: 1) molecular alterations in the amino acid sequence at specific sites; 2) stimulation with anti-peptide antibodies; 3) over-expression in in vitro systems; and 4) over-expression of the coupling G proteins. These other means simulate
5 the stabilizing effect of the signalling molecule to keep the receptor in the active, coupled, state. Such stabilization in the active state is termed "constitutive receptor activation".

Several features distinguish the constitutively activated receptors. First, they have an affinity for the native signalling molecule and related agonists which
10 is typically greater than that of the native receptors. Second, where several known agonists of varying activity (to the native receptor) were known, it was found that the greater the initial activity of the agonist, the greater was the increase in its affinity for the constitutively activated receptor. Third, the affinity
15 of the constitutively activated receptor for antagonists is not increased over the affinity for the antagonist of the native receptor. Fourth, the constitutively activated receptors remain coupled to the second messenger pathway and produce a biological response even in the absence of the signalling molecule or other agonist.

The importance of constitutively activated receptors to biological research
20 and drug discovery cannot be overstated. First, these receptors provide an opportunity to study the structure of the active state and provide insights into how the receptor is controlled and the steps in receptor activation. Second, the constitutively active receptors allow study of the mechanisms by which coupling to G proteins is achieved as well as how G protein specificity is determined.
25 Third, mutated constitutively active receptors are now recognized in disease states. Study of constitutively activated receptors has demonstrated that many mutations may lead to constitutive activation and that a whole range of activation is possible.

Fourth, the existence of constitutively active receptors provides a novel screening
30 mechanism with which compounds which act to increase or decrease receptor activity can be identified and evaluated. Such compounds may become lead compounds for drug research. Finally, studying the affect of classical antagonists

(compounds previously identified as, in the absence of agonist, binding to the receptor but causing no change in receptor activity, and, in the presence of agonist, competitively decreasing the activity of a receptor) and other drugs used as treatments on the constitutively active receptors has led to the discovery that

5 there are compounds, inverse agonists, which decrease the constitutive activity of the active state of the receptors but which have no or little effect on the inactive state. The difference between antagonists, which act on the inactive state, and inverse agonists, which act on the active state, is only discernable when the receptor exhibits constitutive activity. These inverse agonists,

10 identifiable with constitutively active receptors, present an entirely new class of potential compounds for drug discovery.

About 10 years ago, it was recognized that neurotransmitter receptors can be divided into two general classes depending on the rapidity of their response. Fast receptors were identified with ion channels and mediate millisecond

15 responses while slower receptors were identified with G protein-coupled receptors. These G protein-coupled receptors include certain subtypes of the adrenergic as well as the muscarinic cholinergic (M1 - M5), dopaminergic (D1 - D5), serotonergic (5-HT1, 5-HT2, 5-HT4 - 5-HT7) and opiate (δ , κ , and μ) receptors. Each of these G protein-coupled neurotransmitter receptors has been

20 associated with profound changes in mental activity and functioning, and it is believed that abnormal activity of these receptors may contribute to certain psychiatric disorders. Consequently, the elucidation of the mechanism of action of these receptors has been the focus of vigorous research efforts.

Serotonin receptors are of particular importance. Serotonin-containing cell

25 bodies are found at highest density in the raphe regions of the pons and upper brain stem. However, these cells project into almost all brain regions and the spinal column. Serotonin does not cross the blood-brain barrier and is synthesized directly in neurons from L-tryptophan. In the CNS serotonin is thought to be involved in learning and memory, sleep, thermoregulation, motor activity, pain,

30 sexual and aggressive behaviors, appetite, neuroendocrine regulation, and biological rhythms. Serotonin has also been linked to pathophysiological conditions such as anxiety, depression, obsessive-compulsive disorders,

schizophrenia, suicide, autism, migraine, emesis, alcoholism and neurodegenerative disorders. Presently several drugs are used to modify serotonin receptors: 1) 5-HT₁: sumatriptan for treatment of migraine, ipsapirone and buspirone for treatment of anxiety; 2) 5-HT₂: clozapine and risperidone for treatment of schizophrenia; and 3) 5-HT₃: odanestron for the prevention of emesis in chemotherapy.

To date, fourteen serotonin receptors have been identified in 7 subfamilies based on structural homology, second messenger system activation, and drug affinity for certain ligands. The 5-HT₂ subfamily is divided into 3 classes: 5-HT_{2A}, 5-HT_{2B}, and 5-HT_{2C}. 5-HT_{2A} and 5-HT_{2C} receptor antagonists are thought to be useful in treating depression, anxiety, psychosis, and eating disorders. 5-HT_{2A} and 5-HT_{2C} receptors exhibit 51% amino acid homology overall and approximately 80% homology in the transmembrane domains. The 5-HT_{2C} receptor was cloned in 1987 and led to the cloning of the 5-HT_{2A} receptor in 1990. Studies of the 5-HT_{2A} receptor in recombinant mammalian cell lines revealed that the receptor possessed two affinity states, high and low. Both the 5-HT_{2A} and 5-HT_{2C} receptors are coupled to phospholipase C and mediate responses through the phosphatidylinositol pathway. Studies with agonists and antagonists display a wide range of receptor responses suggesting that there is a wide diversity of regulatory mechanisms governing receptor activity. The 5-HT_{2A} and 5-HT_{2C} receptors have also been implicated as the site of action of hallucinogenic drugs.

Much of the knowledge about the structure of G protein-coupled receptors has come from the study of the β_2 -adrenergic receptor. Over the last several years, site-directed mutagenesis has been used to try to determine the amino acid residues important for ligand binding in both the β_2 -adrenergic and 5-HT_{2A} receptors. In addition, studies have suggested that in a native (inactive) state of G protein-coupled receptors, the third intracellular loop is tucked into the receptor and is not available for interaction with the G protein. A change of receptor conformation (active) results in the availability or exposure of the C-terminal region of the third intracellular loop.

In 1990 Cotecchia et al.¹ were studying the G protein specificity determining characteristics of the third intracellular loop by creating chimeric

receptors in which the third intracellular loops had been exchanged between the α_1 -adrenergic receptor and the β_2 -adrenergic receptor. The specific G protein coupled activation was essentially switched between the two receptors. While attempting to determine which portions of the loop were responsible for the specificity, Cotecchia et al. discovered an unexpected phenomena; namely that the modification in the third intracellular loop of the α_1 -adrenergic receptor of three residues, Arg288, Lys290, and Ala293, created a mutant receptor with two orders of magnitude greater affinity for agonist and which coupled to the second messenger system even in the absence of agonist. These modifications were made in the carboxy end of the third cytoplasmic loop adjacent to the sixth transmembrane helix. The changes responsible for this increase were isolated to either a Ala293 \rightarrow Leu or a Lys290 \rightarrow His mutation. Thus, a constitutively active state of a G protein-coupled neuroreceptor had been created. Subsequently, Kjelsberg et al.² demonstrated that mutation of the amino acid at position 293 in the α_{1B} -adrenergic receptor to any other of the 19 amino acids also produced a constitutively active state. Subsequently, mutations in the β_2 -adrenergic receptor near the carboxy end of the third cytoplasmic loop have also been shown by Samama et al.³ to constitutively activate this receptor.

When foci resulting from constitutively active α_{1B} -adrenergic receptors were injected into nude mice, tumor formation occurred. Over the past 5 years, since the discovery that several thyroid adenomas contained mutations of the thyroid stimulating hormone (TSH) receptor, constitutively activated receptors have been found associated with several human disease states. The mutations responsible for these disease states have been found in the transmembrane domains and intracellular loops. For the TSH receptor, mutations at 13 different amino acid positions have been found in the transmembrane domain, the third intracellular loop, and the second and third extracellular loops. Clearly, constitutively activating mutations are not limited to the third intracellular loop and the critical site for constitutive activation varies with each G protein-coupled receptor. The importance of the initial observations was well stated in Cotecchia et al.¹: "Such mutations might not only help to illuminate the biochemical mechanisms involved in receptor-G protein coupling but also provide models for how point mutations

might activate potentially oncogenic receptors."

In light of the above referenced discoveries, the importance and utility of discovering other constitutively activated neuronal receptors cannot be understated. However, the hope that other neuronal receptors could be easily and readily mutated to a constitutively active form by mutations in the third cytoplasmic loop was destroyed by the report of Burstein et al.⁴ in 1995 of a comprehensive mutational approach to the G protein coupled M5 muscarinic acetylcholine receptor. In that approach, Burstein et al. had randomly and comprehensively mutated the C-terminal region of the third intracellular loop of the M5 muscarinic acetylcholine receptor, but no constitutive activating mutations were found.

Definition: CONSTITUTIVELY ACTIVATED RECEPTOR shall mean a G protein-coupled receptor which: 1) exhibits an increase in basal activity of the second messenger pathway in the absence of agonist above the level of activity observed in the wild type receptor in the absence of agonist; 2) may exhibit an increased affinity and potency for agonists; 3) exhibits an unmodified or decreased affinity for antagonists; and 4) exhibits a decrease in basal activity by inverse agonists.

SUMMARY OF THE INVENTION

Constitutively active forms of the rat 5-HT_{2A} and 5-HT_{2C} serotonin receptors have been obtained by a site-directed mutational method that will permit the constitutive activation of all mammalian G protein-coupled serotonin receptors. An amino acid position that will lead to a successful mutation in the serotonin receptor may be identified by alignment of the serotonin receptor against the amino acid sequence of the α_{1B} -adrenergic receptor. Mutating the amino acid in the serotonin receptor which corresponds to the most sensitive position in the α_{1B} -adrenergic receptor, alanine 293, yields a constitutively active serotonin receptor. A strongly constitutively active serotonin receptor is achieved when the mutation in the serotonin receptor is to one of the amino acids which produces the highest level of basal activation in constitutively activated α_{1B} -adrenergic receptors. Successful constitutive activation of the serotonin receptor can be shown by increased high basal levels of second messenger activity in the absence of agonist, increased affinity and potency for agonists, and an unmodified or

decreased affinity for antagonists. While standard methods of site-directed mutagenesis may be employed, the careful placement of restriction sites in the primer permits the more rapid and direct determination of the clone containing the desired mutated receptor.

5 It is the object of this invention to provide a general methodology for obtaining constitutively active forms of the G protein-coupled mammalian monoamine receptors.

It is a further object of this invention to provide a general methodology for obtaining constitutively active forms of the G protein-coupled mammalian
10 serotonin receptors.

It is another object of this invention to provide a constitutively active 5-HT_{2A} serotonin receptor.

It is a further object of this invention to provide a constitutively active 5-HT_{2C} serotonin receptor.

15 Yet another object of this invention is to provide a method for rapidly identifying the clone containing the desired mutated receptor.

These and other achievements of the present invention will become apparent from the detailed description which follows.

DESCRIPTION OF THE FIGURES

20 Figure 1A shows the full DNA sequence for the rat 5-HT_{2A} serotonin receptor including the 5' and 3' untranslated regions with the translated codons underlined. Figure 1B shows the translated amino acid sequence for the rat 5-HT_{2A} receptor.

Figure 2A shows the full DNA sequence for the rat 5-HT_{2C} serotonin
25 receptor including the 5' and 3' untranslated regions with the translated codons underlined. Figure 2B shows the translated amino acid sequence for the rat 5-HT_{2C} receptor.

Figure 3A shows the full DNA sequence for the rat α_{1B} -adrenergic receptor including the 5' and 3' untranslated regions with the translated codons
30 underlined. Figure 3B shows the translated amino acid sequence for the rat α_{1B} -adrenergic receptor.

Figure 4 shows the amino acid sequences for part of the C-terminal third

intracellular loop and transmembrane domain VI for the 5-HT_{2A} and 5-HT_{2C} receptors aligned opposite the corresponding part of the α_{1b} -adrenergic receptor with numerals representing the amino acid positions in each receptor.

5 Figure 5 shows a schematic outline of the 5-HT_{2A} site-directed mutagenesis procedure.

Figure 6 shows a schematic outline of the 5-HT_{2C} site-directed mutagenesis procedure.

10 Figure 7 shows the competition curves of 5-HT for ³H-ketanserin labeled native and mutant 5-HT_{2A} receptors. 0.5 nM ³H-ketanserin was used to label the native and mutant receptors transiently transfected in COS-7 cells.

Figure 8 shows the radioligand binding data of ³H-ketanserin labeled native and mutant 5-HT_{2A} receptors in the presence of agonists and antagonists. 0.5 nM ³H-ketanserin was used to label the native and mutant 5-HT_{2A} receptors expressed in COS-7 cells.

15 Figure 9 shows the stimulation of IP production in COS-7 cells expressing native or mutant 5-HT_{2A} receptors. IP production assays were performed using anion-exchange chromatography. The data are expressed as percent of maximal IP stimulation produced by 10 μ M 5-HT.

20 Figure 10 shows the basal activity and 5-HT stimulation of the native and mutant 5-HT_{2A} receptors. IP levels were measured in COS-7 cells with vector alone, native 5-HT_{2A} receptors, or mutant 5-HT_{2A} receptors. The data are expressed as dpms of IP stimulation minus basal levels of IP produced by vector. Basal activity of vector alone was typically 400 dpms.

25 Figure 11 shows a saturation analysis of ³H-ketanserin labeled native and cys \rightarrow lys mutant receptors. Bmax values were determined by a BCA assay.

Figure 12 shows the competition curves of 5-HT for ³H-mesulergine labeled native and mutant 5-HT_{2C} receptors. 1 nM ³H-mesulergine was used to label the native and mutant receptors transiently transfected in COS-7 cells.

30 Figure 13 shows the radioligand binding analysis of native and mutant 5-HT_{2C} receptors. Native and mutant 5-HT_{2C} receptors expressed in COS-7 cells were labeled with 1 nM ³H-mesulergine. 5-MT = 5-methoxytryptamine.

Figure 14 shows the 5-HT stimulation of IP production in COS-7 cells

transfected with the ser \rightarrow lys or ser \rightarrow phe mutated receptors. Cells were labeled with ^3H -myoinositol and challenged with 5-HT (0.1 nM - 10 nM). Total IP production was measured by anion exchange chromatography.

Figure 15 shows the EC_{50} values for the 5-HT stimulation of IP production in COS-7 cells transfected with native, mutant ser \rightarrow lys receptor, and mutant ser \rightarrow phe receptor. Figure 15 also shows the results of ^3H -mesulergine saturation analyses. Saturation experiments were performed using ^3H -mesulergine (0.1 nM - 5.0 nM).

Figure 16 shows the effect of the ser \rightarrow lys and ser \rightarrow phe mutations on basal levels of IP production by the mutated 5-HT_{2C} receptors. IP levels were measured in COS-7 cells with vector alone, native 5-HT_{2C} receptors, or mutant 5-HT_{2C} receptors. The data are expressed as dpms of IP stimulation minus basal levels of IP produced by vector.

Figure 17 shows the inverse agonist activity of spiperone and ketanserin on the mutated constitutively active 5-HT_{2A} cys \rightarrow lys receptor. Parallel transfections with the native 5-HT_{2A} receptor were performed to determine native basal activity which was then subtracted from the mutant receptor basal activity to determine constitutive stimulation.

Figure 18 shows the inverse agonist activity of chlorpromazine, haloperidol, loxapine, spiperone, clozapine and risperidone on the mutated constitutively active 5-HT_{2A} cys \rightarrow lys receptor.

Figure 19 shows the inverse agonist activity of mianserin and mesulergine on the mutated constitutively active 5-HT_{2C} ser \rightarrow lys receptor both in the presence and absence of 5-HT.

Figure 20A sets forth the full DNA sequence for the human 5-HT_{2A} serotonin receptor with the translated codons underlined. The sixth transmembrane domain conserved sequence of WxPFFI is indicated with block letters. Figure 20B shows the translated amino acid sequence for the human 5-HT_{2A} receptor.

Figure 21A sets forth the full DNA sequence for the human 5-HT_{2C} serotonin receptor with the translated codons underlined. The sixth transmembrane domain conserved sequence of WxPFFI is indicated with block

letters. Figure 21B shows the translated amino acid sequence for the human 5-HT_{2C} receptor.

Figure 22 is the amino acid sequence of the 5-HT_{2A} cys → lys mutant receptor with the mutated amino acid shown as a larger outlined letter.

5 Figure 23 is the DNA sequence of the 5-HT_{2A} cys → lys mutant receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #322 lysine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated.

10 Figure 24 is the DNA sequence of the 5-HT_{2A} cys → lys mutant receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #322 lysine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated. In addition the two bases which were mutated to create the Sca1 site
15 are shown as larger outlined letters and are indicated with arrows.

Figure 25 is the amino acid sequence of the 5-HT_{2A} cys → arg mutant receptor with the mutated amino acid shown as a larger outlined letter.

Figure 26 is the DNA sequence of the 5-HT_{2A} cys → arg mutant receptor including the 5' and 3' untranslated regions with the translated codons
20 underlined. The bases specifying the #322 arginine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated.

Figure 27 is identical to Figure 26 since the AGG mutation introduced for arginine creates an Mnl1 restriction site by itself at #319.

25 Figure 28 is the amino acid sequence of the 5-HT_{2A} cys → glu mutant receptor with the mutated amino acid shown as a larger outlined letter.

Figure 29 is the DNA sequence of the 5-HT_{2A} cys → glu mutant receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #322 glutamic acid mutant are shown as
30 larger outlined letters, and the starting and ending locations of the primer are also indicated.

Figure 30 is the DNA sequence of the 5-HT_{2A} cys → glu mutant receptor

including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #322 glutamic acid mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated. In addition the additional base which was mutated to create the Rsa1
5 site is shown as a larger outlined letter and is indicated with an arrow.

Figure 31 is the amino acid sequence of the 5-HT_{2C} ser → lys mutant receptor with the mutated amino acid shown as a larger outlined letter.

Figure 32 is the DNA sequence of the 5-HT_{2C} ser → lys mutant receptor including the 5' and 3' untranslated regions with the translated codons
10 underlined. The bases specifying the #312 lysine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated.

Figure 33 is the DNA sequence of the 5-HT_{2C} ser → lys mutant receptor including the 5' and 3' untranslated regions with the translated codons
15 underlined. The bases specifying the #312 lysine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated. In addition the base which was mutated to create the Sca1 site is shown as a larger outlined letter and is indicated with an arrow.

Figure 34 is the amino acid sequence of the 5-HT_{2C} ser → phe mutant
20 receptor with the mutated amino acid shown as a larger outlined letter.

Figure 35 is the DNA sequence of the 5-HT_{2C} ser → phe mutant receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #312 phenylalanine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also
25 indicated.

Figure 36 is the DNA sequence of the 5-HT_{2C} ser → phe mutant receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #312 phenylalanine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also
30 indicated. In addition the base which was mutated to create the Sca1 site is shown as a larger outlined letter and is indicated with an arrow.

DETAILED DESCRIPTION OF THE INVENTION

Despite the disappointing results obtained by Burstein in mutating positions in the third intracellular loop of the M5 muscarinic acetylcholine receptor, the present inventive efforts focused on finding mutations at the carboxy end of the third intracellular loop near the sixth transmembrane helix in the serotonin
5 receptors. DNA and amino acid sequences for rat 5-HT_{2A} and 5-HT_{2C} serotonin receptors were obtained from GeneBank as was the DNA and amino acid sequence for the α_{1B} -adrenergic receptor. Figures 1, 2, and 3 list the full DNA and translated amino acid sequences for these receptors.

10 Receptor Alignment:

As noted above, Cotecchia et al. had identified amino acid position number 293 in the third intracellular loop adjoining the sixth transmembrane domain in the α_{1B} -adrenergic receptor as a critical position, mutation of which lead to constitutive activity. However, the length of the serotonin receptors is different
15 than the α_{1B} -adrenergic receptor, and even had they been the same, matching the ends would not necessarily provide a structural or functional match. What was important was to find an alignment method which made sense in terms of locating the equivalent functional site to position 293 of the α_{1B} -adrenergic receptor in the serotonin receptors.

20 A meaningful alignment method has been discovered based upon the fact that the transmembrane domains are highly conserved in G protein-coupled receptors. A series of conserved amino acid positions were identified in the sixth transmembrane domain which permit alignment of the transmembrane domain and the adjacent third intracellular loop between receptors. In Figure 5 the
25 conserved sixth transmembrane domain amino acid sequence WxPFFI (x may be variable) has been used to align the three receptors. Alignment using this sequence also aligns the LGIV sequence found at the intracellular beginning of the sixth transmembrane domain which is connected to the third intracellular loop. This alignment indicates that in the 5-HT_{2A} receptor the cysteine at position #322
30 corresponds to the alanine at position #293 in the α_{1B} -adrenergic receptor. In the 5-HT_{2C} receptor, the corresponding amino acid is a serine at position #312.

It should be noted that position 293 is not the only position in the α_{1B} -

adrenergic receptor which, when mutated, produced a constitutively active receptor. While Cotecchia et al.¹ reported that the A293L mutation produced the greatest constitutive activation, they also noted that the K290H mutation also induced dramatic constitutive activity. There are clearly other sites in the third intracellular loop of each of these receptors that can be mutated. In the future, other sites on other receptors may be reported. However, the alignment methodology presented above should serve to permit the structural correlation between different receptors so that information gleaned from one receptor may be utilized to mutate another receptor. However, the evidence presently available suggests that the third position removed from the beginning of the transmembrane domain represented by position 293 in the α_{1B} -adrenergic receptor seems to play a crucial role in the binding and activation of the coupled G protein, and that mutations introduced at that position alter the tertiary structure of the region.

As noted earlier, Kjelsberg et al.² further demonstrated that substitution of any of the 19 amino acids at position 293 of the α_{1B} -adrenergic receptor produced constitutive activity. However, the relative activity increased in the following order of amino acids: S, N, D, G, T, H, W, Y, P, V, L, M, Q, I, F, C, R, K, and E. In that study, replacing the native amino acid with amino acids having long basic or acidic side chains produced the greatest degree of constitutive activity, while amino acids with aromatic substituents produced an intermediate degree of constitutive activity. It is proposed that this order, with minor variations, exists for most G protein-coupled receptors due to the importance of the third position removed from the beginning of the transmembrane domain. A reasonable starting place for mutating receptors should therefore involve mutation to one of the amino acids at the most active end of the above list. Further, the tertiary structure of the region may be significantly altered by substituting an amino acid with longer side chains or of different polarity from the native amino acid.

Efficient Screening of Mutant Receptors:

When performing site-directed mutagenesis, it is common (and necessary) laboratory practice to fully sequence the cloned receptor to confirm that the mutation has been incorporated. However, because colonies containing the

mutant receptor cannot be distinguished from those that do not, it is necessary to sequence each colony. A method, outlined schematically by way of example in Figure 5 for the 5-HT_{2A} cys → lys receptor mutation and in Figure 6 for the 5-HT_{2C} ser → lys and ser → phe receptor mutations, has been devised that rapidly and easily eliminates most non-mutated colonies, and from those remaining, identifies the mutant colony so that unnecessary sequencing is avoided. A two-pronged approach is used. The first prong is designed to prevent non-mutated vector from being incorporated during the first transformation by digesting the vector. E coli will only incorporate uncut (circular) plasmid DNA. Recognizing the limitations of the first prong, namely, that all restriction digests are not 100% complete so that some of the colonies at the end of the procedure will contain native DNA instead of mutant DNA, the second prong is designed to easily identify among the remaining colonies, those colonies containing the desired mutation after a second transformation.

To begin, a unique restriction site, not occurring in the native amino acid sequence, is incorporated into the mutant. It is possible to introduce the unique restriction site because of the degeneracy of the genetic code. The unique restriction site is ideally located within or near the amino acid(s) which specify the structural mutation which is being introduced into the mutant. Thus, the restriction site can be located on the same mutagenic primer as the structural mutation.

In addition, during the initial annealing, a second primer is used to remove a restriction site specific to the vector being used. When the second strand is synthesized with polymerase and ligase, only the second strand of the vector (the one not containing the mutations) will contain the original vector restriction site. Subsequently, after transformation, the colonies can be treated with the restriction enzyme specific for the vector site and only those resulting from the wildtype vector will be digested. Digested (cut) DNA will not be taken up by E. coli during the second transformation step. The colonies containing the mutated vector will not be digested and will be taken up by E. coli during the final transformation step.

Each resulting colony can be tested to see whether the restriction enzyme,

which recognizes the unique site introduced by the mutated primer, digests the DNA. Only samples from colonies containing the desired mutation will be digested. These colonies can then be sequenced to confirm the insertion of the mutated amino acid. It is unnecessary to sequence colonies whose DNA is not digested by the restriction enzyme. This procedure yields a much more highly efficient method by saving both time and expense of sequencing every colony which results from the transformation experiment.

Measurement of Receptor-Coupled Second Messenger Activation:

In order to measure the stimulation produced through the 5-HT_{2A} and the 5-HT_{2C} receptors, an assay was utilized which measures the accumulation of inositol phosphates, the product that is formed when phosphatidylinositol 4,5-bisphosphate is hydrolyzed to DAG and IP. This assay was established by Berridge and coworkers (1983) in studies of the blowfly salivary glands, and found to be an accurate measurement of the stimulation of phospholipase C through receptor activation. ³H-myoinositol is incorporated into the cell membrane by conversion to phosphatidylinositol 4,5-bisphosphate and upon receptor activation, is cleaved by phospholipase C to yield two products: diacylglycerol and ³H-inositol 1,4,5 triphosphate (IP₃).

Inositol-free media must be used for this assay because unlabeled inositol, which is normally found in many commercially available media, can result in less than maximal incorporation of radiolabeled inositol into the cell membrane, resulting in a reduction in the amount of ³H-IP that would be detected. The ³H-IP is recovered by anion-exchange chromatography in which IP is separated from anion-exchange resin using washes of increasing concentrations of formate.

IP₃ is rapidly hydrolyzed to IP₂ by an inositol triphosphatase which is then converted to IP by inositol bisphosphatase. Because IP₃ is hydrolyzed so quickly, accumulation of IP would be hard to measure unless the cycle of IP to inositol and phosphate is blocked. Lithium is used in this assay to block the enzyme which converts IP to inositol and phosphate (myo-inositol monophosphatase). This ensures that IP levels can accumulate and be experimentally measured and are not undergoing the normal rapid degradation pathway. These experiments are also performed in serum free media in order to remove serotonin that can be found in

serum which would complicate experimental results.

The total IP levels were measured in order to obtain an accurate measurement of the total amount of stimulation that occurred. The actual experimental conditions and concentrations of reagents used in this assay are set forth in the methods and materials sections under each example below.

Example 1: Constitutive Activation Of The 5-HT_{2A} Receptor:

Three separate mutations of the 5-HT_{2A} receptor were made. The cysteine at position 322 was mutated to lysine, glutamate, and arginine.

Materials and Methods For Site-directed Mutagenesis:

- 10 The rat 5-HT_{2A} receptor cDNA was ligated into the mammalian expression vector pcDNA3 (Invitrogen) using EcoR1 (GIBCO). This construct served as the native template for site-directed mutagenesis performed using Clontech's transformer kit. Mutagenic primers (Midland Certified Reagent Company) were designed as follows: the C322K primer was complementary to amino acid nos.
- 15 318-329 of the native 5-HT_{2A} cDNA, while changing amino acid no. 322 from cysteine (TGC) to lysine (AAG). The same primer was designed to incorporate a Sca1 restriction site using amino acid nos. 323 and 324 by changing the third base in amino acid no. 323, lysine, from AAG to AAA and the third base in amino acid no. 324, valine from GTG to GTA. The C322E and C322R were designed
- 20 complementary to amino acid nos. 319-330 of the native 5-HT_{2A} cDNA, while changing amino acid no. 322 from cysteine (TGC) to glutamate (GAG) and arginine (AGG). In the C322E primer, an Rsa1 site was introduced by changing the third base in amino acid no. 324, valine, from GTG to GTA. The C322R mutation in the primer created an Mnl1 site, by itself, at amino acid no. 319. The
- 25 selection primer, complementary to bases 4,871-4,914 of the pcDNA3 vector, was designed to remove a unique PVUI site by changing base G to T at location 4891. Phosphorylated primers were annealed to 10 ng of alkaline-denatured plasmid template by heating to 65°C for 5 min and cooling slowly to 37°C. Mutant DNA was synthesized using T4 DNA polymerase and ligase (Clontech) by
- 30 incubating for 1 hr at 37°C, followed by digestion with PVU1 (GIBCO) and transformation of BMH71-18mutS E. coli (Clontech). Plasmid was purified using the Wizard miniprep kit (Promega), digested with PVU1, and used to transform

DH5(E.Coli (GIBCO). Individual colonies were isolated and plasmid DNA was digested with SCA1, Mnl1 or Rsa1 to screen for C322K, C322E and C322R mutations, respectively (GIBCO). DNA sequencing (Sequenase version 2.1 kit,USB, ³⁵Sd-ATP, New England Nuclear) was performed to confirm the

- 5 incorporation of lysine, glutamate, or arginine at amino acid no. 322. Sequencing reactions were run on a 5% acrylamide/bis (19:1) gel (Bio-Rad) for 2 hr at 50°C, dried for 2 hr at 80°C, and exposed on Kodak Biomax MR film for 24 hr at -80°C.

In Figure 22 is shown the amino acid sequence of the 5-HT_{2A} cys → lys mutant receptor with the mutated amino acid shown as a larger outlined letter.

- 10 Figure 23 shows the resulting DNA sequence of the 5-HT_{2A} cys → lys mutant receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #322 lysine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated. In addition to showing the mutated DNA sequence of the 5-HT_{2A} cys →
- 15 lys mutant receptor, Figure 24 shows the two bases, which were mutated to create the Sca1 site, as larger outlined letters and are indicated with arrows.

In Figure 25 is shown the amino acid sequence of the 5-HT_{2A} cys → arg mutant receptor with the mutated amino acid shown as a larger outlined letter.

- Figure 26 shows the resulting DNA sequence of the 5-HT_{2A} cys → arg mutant
- 20 receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #322 arginine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated. Figure 27 showing the added restriction site is identical to Figure 26 since the arginine mutation to AGG creates, by itself, an Mnl1 restriction site at
- 25 #319.

In Figure 28 is shown the amino acid sequence of the 5-HT_{2A} cys → glu mutant receptor with the mutated amino acid shown as a larger outlined letter.

- Figure 29 shows the resulting DNA sequence of the 5-HT_{2A} cys → glu mutant
- 30 receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #322 glutamic acid mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also indicated. Figure 30 shows the additional base mutation introduced in amino

acid 324 to create an Rsa1 site. The base mutation is indicated by a larger outlined letter and an arrow.

Cell culture and transfection:

COS-7 cells were grown in Dulbecco's modified Eagle's medium (DMEM, Sigma) with 10% fetal bovine serum (Sigma) in 5% CO₂ at 37°C and subcultured 1:8 twice a week. Twenty-four hours before transfection, cells were seeded at 30% confluence in 100-mm dishes for radioligand binding assays or at 10⁵ cells per well in 24-well cluster plates for IP production assays. Cells were transfected with native or mutant 5-HT_{2A} cDNA using Lipofectamine (GIBCO). This was accomplished by combining 20 µl of Lipofectamine with 2.5 µg of plasmid per 100-mm dish or 2 µl of Lipofectamine with 0.25 µg of plasmid per well. Transfections were performed in serum-free DMEM for 4 hr at 37°C.

Radioligand binding:

Thirty-six hours after transfection, membranes were prepared from COS-7 cells by scraping and homogenizing in 50mM Tris-HCl/5mM MgCl₂/0.5mM EDTA, pH 7.4 (assay buffer), and centrifugation at 10,000xg for 30 min. Membranes were resuspended in assay buffer, homogenized, and centrifuged again. After resuspension in assay buffer, 1-ml membrane aliquots (approximately 10 µg of protein measured by bicinchoninic acid assay) were added to each tube containing 1ml of assay buffer with 0.5nM [³H] ketanserin and competing drugs. 10µM spiperone was used to define non-specific binding. Saturation experiments were performed by using [³H]ketanserin (0.1-5.0nM). Samples were incubated at 23°C for 30 minutes, filtered on a Brandel cell harvester, and counted in Ecoscint cocktail (National Diagnostics) in a Beckman liquid scintillation counter at 40% efficiency.

Phosphatidylinositol hydrolysis:

Inositol phosphate (IP) production was measured using a modified combination of the methods of Berridge et al. (1982) and Conn and Sanders-Bush (1985). In brief, 24 h after transfection, cells were washed with phosphate-buffered saline (PBS) and labeled with 0.25 µCi/well of myo-[³H]inositol (New England Nuclear) in inositol free/serum-free DMEM (GIBCO) for 12 h at 37°C. HPLC analysis of this culture medium, after incubation, has been reported to

contain $< 10^{-10}$ M 5-HT (Barker et al. 1994). After labeling, cells were washed with PBS and preincubated in inositol-free/serum-free DMEM with 10mM LiCl and 10 μ M pargyline (assay medium) for 10 min at 37°C. When antagonists were used, they were added during the 10-min preincubation period. 5-HT (Sigma), or
5 assay medium alone, was added to each well and incubation continued for an additional 35 min (Westphal et al., 1995). Assay medium was removed and cells were lysed in 250 μ l of stop solution (1 M KOH/18mM sodium borate/3.8mM EDTA) and neutralized by adding 250 μ l of 7.5 % HCl. The contents of each well were extracted with 3 volumes of chloroform/methanol (1:2), centrifuged 5 min
10 at 10,000xg, and the upper layer loaded onto a 1-ml AG1-X8 resin (100-200 mesh, Bio-Rad) column. Columns were washed with 10ml of 5 mM myo-inositol and 10ml of 5 mM sodium borate/60mM sodium formate. Total IPs were eluted with 3ml of 0.1 M formic acid/1 M ammonium formate. Radioactivity was measured by liquid scintillation counting in Ecoscint cocktail.

15 Demonstration of Constitutive Activation:

Constitutive activity of the mutated 5-HT_{2A} receptors is demonstrated by the fact that the mutated receptors exhibit all the hallmark characteristics established for constitutive activation: a showing of increased agonist affinity, increased agonist potency, and coupling to the G protein second messenger
20 system in the absence of agonist.

Figure 7 shows the competition curves of 5-HT for ³H-ketanserin labeled native and mutant 5-HT_{2A} receptors. 0.5nM ³H-ketanserin was used to label the native and mutant receptors transiently transfected in COS-7 cells. While the native receptor demonstrated a relatively low affinity for 5-HT (K_i = 293 nM), the
25 three mutant receptors displayed a high affinity for 5-HT with the cys \rightarrow lys mutant exhibiting a 12-fold increase in affinity for 5-HT (K_i = 25 nM), the cys \rightarrow arg mutant exhibiting a 27-fold increase in affinity for 5-HT (K_i = 11 nM). and the cys \rightarrow glu mutant exhibiting a 3.4-fold increase in affinity for 5-HT (K_i = 86 nM).

To determine whether other agonists would display a similar increase in
30 affinity for the mutant receptors, two known agonists (DOM and DOB) were tested with both the native and cys \rightarrow lys mutant. Figure 8 shows the radioligand binding data of ³H-ketanserin labeled native and mutant 5-HT_{2A} receptors in the

presence of agonists and antagonists. 0.5 nM ^3H -ketanserin was used to label the native and mutant 5-HT_{2A} receptors expressed in COS-7 cells. The DOM and DOB agonists show increased affinity for the mutant receptor, as is seen for 5-HT. The K_i for DOM shows a 5-fold increase, while the K_i for DOB shows a 7.4-fold

5 increase.

To determine if the mutant 5-HT_{2A} receptors would exhibit an increase in agonist potency relative to the native 5-HT_{2A} receptor, 5-HT stimulation of the native and mutant 5-HT_{2A} receptors was measured using an IP production assay. Figure 9 shows the stimulation of IP production in COS-7 cells expressing native
10 or mutant 5-HT_{2A} receptors. Both the cys → lys and cys → glu mutant receptor curves exhibit a leftward shift away from the native curve in the 5-HT dose-response indicating that there was an increase in 5-HT potency at the mutant receptors. The cys → lys and cys → glu mutant receptors displayed EC₅₀ values of 25 nM and 61 nM, respectively, as compared to the native 5-HT_{2A} receptor which
15 had an EC₅₀ value of 152 nM.

Figure 10 shows the basal activity and 5-HT stimulation of the native and mutant 5-HT_{2A} receptors. As can be seen, both the cys → lys and the cys → glu mutant 5-HT_{2A} receptors show dramatic increases in basal intracellular inositol phosphate (IP) accumulation compared to the native receptor. The cys → lys
20 mutant receptor produced a 345% (8-fold) increase in IP levels over the vector control. The cys → glu mutant receptor produced a 158% (3.7-fold) increase in IP levels over the vector control. Upon the addition of 10 μM 5-HT, both the native and mutant receptors produced an additional increase in IP production. The basal activity of the cys → lys mutant was 48% of that of the maximally stimulated
25 native 5-HT_{2A} receptor. The basal activity of the cys → glu mutant was 31% of that of the maximally stimulated native 5-HT_{2A} receptor.

In order to determine whether the above results were due to an increase in the number of expressed mutant receptors rather than to a change in the properties of the mutated receptors, saturation curves were generated. Figure 11
30 shows a saturation analysis of ^3H -ketanserin labeled native and cys → lys mutant receptors. B_{MAX} values were determined by a BCA assay. For the native receptor the B_{MAX} = 193 ± 37 fmol/mg, while for the cys → lys mutant receptor, the

$B_{MAX} = 218 \pm 31$ fmol/mg. There is no significant difference in the B_{MAX} values for the native and mutant receptors. The K_D of 3H -ketanserin also did not differ between the native and mutant receptors. These data demonstrate that the results were not due to an increase in number of expressed mutant receptors compared to expressed native receptors.

Thus, the mutated 5-HT_{2A} receptors meet all the criteria for constitutively activated receptors; they show a higher affinity for agonists; they show a higher potency for 5-HT; and they show activation (coupling) of the G protein second messenger pathway (IP production) even in the absence of agonist.

10 Example 2: Constitutive Activation of 5-HT_{2C} Receptor

Materials and Methods For Site-directed Mutagenesis:

The rat 5-HT_{2C} receptor cDNA was ligated into the mammalian expression vector pcDNA3 (Invitrogen) using BamHI (Gibco). This construct served as the native template for site-directed mutagenesis performed using Clonotech's Transformer kit. Mutagenic primers (Midland Certified Reagent Company) were designed complementary to amino acids #308-317 of the native 5-HT_{2C} cDNA, while changing amino acid #312 from serine (TCC) to lysine (AAG) or phenylalanine (TTC). The same primers were designed to incorporate an ScaI restriction site at amino acid #314 by changing the third codon in valine from GTC to GTA. The selection primer, complementary to bases 2081-3017 of the pcDNA3 vector, was designed to remove a unique SmaI site by changing glycine at base 2093 from GGG to GGA. Phosphorylated primers were annealed to 10ng of alkaline denatured plasmid template by heating to 65°C for 5 minutes and cooling slowly to 37°C. Mutant DNA was synthesized using T4 DNA polymerase and ligase (Clonotech) by incubating for 1 hour at 37°C, followed by digestion with SmaI (Gibco) and transformation of BMH71-18mutS E. coli (Clonotech). Plasmid was purified using the Wizard miniprep kit (Promega), digested with SmaI, and used to transform DH5 α E. coli (Gibco). Individual colonies were isolated and plasmid DNA was digested with ScaI to screen for S312K and S312F mutants (Gibco). S312K and S312F mutant plasmids contain an additional ScaI site and appear as two bands (2.3Kb and 7.6Kb) when run on a 1% agarose gel. DNA sequencing (Sequenase version 2.1 kit USB, ^{35}S d-ATP NEN)

was performed to confirm the incorporation of lysine or phenylalanine at amino acid #312. Sequencing reactions were run on a 5% acrylamide/bis (19:1) gel (BioRad) for 2 hours at 50°C, dried for 2 hours at 80°C, and exposed to Kodak Biomax MR film for 24 hours at -80°C.

5 In Figure 31 is shown the amino acid sequence of the 5-HT_{2c} ser → lys mutant receptor with the mutated amino acid shown as a larger outlined letter. Figure 32 shows the resulting DNA sequence of the 5-HT_{2c} ser → lys mutant receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #312 lysine mutant are shown as larger
10 outlined letters, and the starting and ending locations of the primer are also indicated. In addition to showing the mutated DNA sequence of the 5-HT_{2c} ser → lys mutant receptor, Figure 33 shows the base, which was mutated to create the Sca1 site, as a larger outlined letter indicated with an arrow.

In Figure 34 is shown the amino acid sequence of the 5-HT_{2c} ser → phe
15 mutant receptor with the mutated amino acid shown as a larger outlined letter. Figure 35 shows the resulting DNA sequence of the 5-HT_{2c} ser → phe mutant receptor including the 5' and 3' untranslated regions with the translated codons underlined. The bases specifying the #312 phenylalanine mutant are shown as larger outlined letters, and the starting and ending locations of the primer are also
20 indicated. In addition to showing the mutated DNA sequence of the 5-HT_{2c} ser → phe mutant receptor, Figure 36 shows the base, which was mutated to create the Sca1 site, as a larger outlined letter indicated with an arrow.

Cell culture and transfection:

COS-7 cells were grown in Dulbecco's Modified Eagle's Medium (DMEM, Sigma) with 10% fetal bovine serum (Sigma) in 5% CO₂ at 37°C and subcultured
25 1:8 twice a week. Twenty-four hours prior to transfection, cells were seeded at 30% confluence in 100mm dishes for radioligand binding assays or at 10⁵ cells/well in 24 well cluster plates for PI assays. Cells were transfected with native or mutant 5-HT_{2c} cDNA using Lipofectamine (Gibco). This was
30 accomplished by combining 20 µl of lipofectamine with 2.5 µg plasmid per 100mm dish or 2 µl lipofectamine and 0.25 µg plasmid per well. Transfections were performed in serum-free DMEM for 4 hours at 37°C.

Radioligand binding:

Thirty-six hours after transfection, membranes were prepared from COS-7 cells by scraping and homogenizing in 50mM Tris-HCl / 5mM MgCl₂ / 0.5mM EDTA pH 7.4 (assay buffer) and centrifugation at 10,000xg for 30 minutes.

- 5 Membranes were resuspended in assay buffer, homogenized and centrifuged again. Following resuspension in assay buffer, 1 ml membrane aliquots (approximately 10 μ g protein measured by BCA assay) were added to each tube containing 1ml of assay buffer with 1nM ³H-mesulergine and competing drugs. 10 μ M mianserin was used to define non-specific binding. Saturation experiments
- 10 were performed using ³H-mesulergine (0.1nM-5.0nM) or ³H-5-HT (0.1nM-30nM) in the absence or presence of 10 μ M GppNHp (RBI). Samples were incubated at 37°C for 30 minutes, filtered on a Brandel cell harvester, and counted in Ecoscint cocktail (National Diagnostics) in a Beckman liquid scintillation counter at 40% efficiency.

15 Phosphatidylinositol hydrolysis:

- Inositol phosphate (IP) production was measured using a modified combination of the methods of Berridge et al., 1982 and Conn and Sanders-Bush 1985. Briefly, 24 hours after transfection, cells were washed with PBS and labeled with 0.25 μ Ci/well of ³H-myoinositol (NEN) in inositol-free/serum-free
- 20 DMEM (Gibco) for 12 hours at 37°C. Following labeling, cells were washed with PBS and preincubated in inositol-free/serum-free DMEM with 10mM LiCl and 10 μ M pargyline (assay medium) for 10 minutes at 37°C. When antagonists were used they were added during the 10 minute preincubation period. 5-HT (Sigma), or assay medium alone, was added to each well and incubation continued for an
- 25 additional 35 minutes (Westphal et al., 1995). Assay medium was removed and cells were lysed in 250 μ l of stop solution (1M KOH / 18mM NaBorate / 3.8mM EDTA) and neutralized by adding 250 μ l of 7.5% HCl. The contents of each well were extracted with 3 volumes of chloroform:methanol (1:2), centrifuged 5 minutes at 10,000xg, and the upper layer loaded onto a 1ml AG1-X8 resin (100-
- 30 200 mesh, BioRad) column. Columns were washed with 10mls of 5mM myoinositol and 10mls of 5mM NaBorate / 60mM NaFormate. Total IPs were eluted with 3mls of 0.1M formic acid / 1M ammonium formate. Radioactivity was

measured by liquid scintillation counting in Ecoscint cocktail.

Stable Transfection:

Although not yet fully characterized, it has been found possible to create a stable cell line expressing mutant receptors by the following method. The rat
5 5-HT_{2c} cDNA (edited VSI isoform) was used as a template for site-directed mutagenesis to convert amino acid 312 from serine to lysine as previously described. Native and S312K 5-HT_{2c} cDNAs were ligated into the BamHI/EcoRI site of the pZeoSV2+ mammalian expression vector (Invitrogen) containing the zeocin resistance gene. NIH3T3 cells (ATCC) were stably transfected using the
10 high efficiency BES method. Briefly, cells were seeded at 5×10^5 cells/100mm culture dish in complete medium (DMEM/10%FBS) and grown in 5% CO₂ at 37° overnight. Twenty micrograms of pZeoSV2/5-HT_{2c} DNA (linearized with BglII) was mixed with 500 μ l of 0.25M CaCl₂ and 500 μ l of 2x BES solution (50mM N,N-bis-2-hydroxyethyl-2-aminoethanesulfonic acid; 280mM NaCl; 1.5mM
15 Na₂HPO₄; pH to 6.95) and incubated at 25°C for 20 minutes. The solution was added dropwise on top of the cells. The cells were incubated for 20 hours at 35°C in 3% CO₂, washed twice with PBS, complete medium replenished, and incubated for 48 hours at 37°C in 5% CO₂. Cells were split 1:4 into complete medium containing 500 μ g/ml zeocin. Individual colonies were isolated and tested
20 for 5-HT_{2c} receptor expression by ³H-mesulergine binding.

Demonstration of Constitutive Activation:

Constitutive activity of the mutated 5-HT_{2c} receptors is demonstrated by the fact that the mutated receptors also exhibit all the hallmark characteristics established for constitutive activation: a showing of increased agonist affinity,
25 increased agonist potency, and coupling to the G protein second messenger system in the absence of agonist.

Figure 12 shows the competition curves of 5-HT for ³H-mesulergine labeled native and mutant 5-HT_{2c} receptors. 0.5nM ³H-mesulergine was used to label the native and mutant receptors transiently transfected in COS-7 cells. As shown in
30 Figure 12, the 5-HT competition isotherms for ³H-mesulergine labeled ser → lys and ser → phe mutant receptors display a marked leftward shift compared with native receptors. The affinity of 5-HT for ser → lys mutant receptors increased

almost 30-fold from 203 nM in the native to 6.6 nM in the ser → lys mutant. Similarly, but on a smaller scale, the ser → phe mutation resulted in a 3-fold increase in 5-HT affinity to 76 nM.

To determine whether other agonists would display a similar increase in
5 affinity for the mutant receptors, two known agonists, 5-methoxytryptamine and
DOB were tested with the ser → lys mutant. Figure 13 shows the radioligand
binding analysis of native and mutant 5-HT_{2C} receptors in the presence of
agonists and antagonists. Native and mutant 5-HT_{2C} receptors expressed in COS-
7 cells were labeled with 1 nM 3H-mesulergine. The 5-MT and DOB agonists
10 show increased affinity for the mutant receptor, as is seen for 5-HT. 5-methoxy-
tryptamine and DOB display an 89-fold and 38-fold increase, respectively, in
affinity for the ser → lys mutant receptors.

To determine if the mutant 5-HT_{2C} receptors would exhibit an increase in
agonist potency relative to the native 5-HT_{2C} receptor, 5-HT stimulation of the
15 native and mutant 5-HT_{2C} receptors was measured using an IP production assay.
Figure 14 shows the stimulation of IP production in COS-7 cells expressing native
or mutant 5-HT_{2C} receptors. Both the ser → lys and ser → phe mutant receptor
curves exhibit a leftward shift away from the native curve in the 5-HT dose-
response indicating that there was an increase in 5-HT potency for the mutant
20 receptors. The shifts were similar in magnitude to the shifts in the 5-HT
competition binding isotherms. Figure 15 shows the 5-HT stimulation of IP
production in COS-7 cells transfected with the ser → lys or ser → phe mutated
receptors. As shown in Figure 15, the EC₅₀ value for 5-HT mediated stimulation of
IP production increased from 70 nM in cells transfected with native receptors to
25 2.7 nM in the ser → lys mutant and 28 nM in the ser → phe mutant.

Figure 16 shows the effect of the ser → lys and ser → phe mutations on
basal levels of IP production by the mutated 5-HT_{2C} receptors. Cells transfected
with native 5-HT_{2C} receptors displayed a small increase (9%, 225dpm) in basal IP
production over cells transfected with vector alone. Transfection with ser → lys
30 and ser → phe mutant 5-HT_{2C} receptors resulted in 5-fold and 2-fold increases,
respectively, in basal levels of IP production when compared with cells expressing
native 5-HT_{2C} receptors. Basal levels of IP stimulated by ser → lys mutant

receptors represented 50% of total IP production stimulated by native receptors in the presence of 10 μ M 5-HT. 5-HT stimulated IP production 10 fold over basal levels in cells transfected with native receptors and 2-fold over basal levels in cells transfected with ser \rightarrow lys mutant receptors. However, 5-HT elicited the same maximal IP response in cells transfected with native or mutant receptors.

Since receptor density can influence agonist binding affinity and potency in stimulating second messenger systems, saturation curves were generated. Therefore, 3 H-mesulergine saturation analyses and Scatchard transformations were performed in parallel to control for variations in transfection efficiency and receptor expression levels. As shown in Figure 15, the 5-HT_{2C} receptor density was greater in cells transfected with native receptors than in cells transfected with either the ser \rightarrow lys or the ser \rightarrow phe mutant receptors. These data indicate that the increase in agonist binding affinity and potency of the mutated receptors did not result from increased receptor expression, but directly resulted from the mutations.

Thus, like the mutated 5-HT_{2A} receptors, the mutated 5-HT_{2C} receptors meet all the criteria for constitutively activated receptors; they show a higher affinity for agonists; they show a higher potency for 5-HT; and they show activation (coupling) of the G protein second messenger pathway (IP production) even in the absence of agonist.

Inverse Agonism at Constitutively Activated Serotonin Receptors

As noted above, the discovery and elucidation of the mechanisms of action of constitutively activated receptors has led to the recognition of a new class of receptor antagonists, identified as inverse agonists. The mutated 5-HT_{2A} and 5-HT_{2C} receptors of this invention were used to test the activity of known serotonin receptor antagonists. Figure 8 shows the binding affinities of four known 5-HT_{2A} antagonists to the native and cys \rightarrow lys mutant 5-HT_{2A} receptors. There is an apparent decrease in the binding affinity of methysergide and mianserin at the mutant 5-HT_{2A} receptors, but no change in binding affinity for spiperone and ketanserin. However, as shown in Figure 17, both spiperone and ketanserin reversed the constitutive stimulation of IP production in cells expressing the mutant 5-HT_{2A} receptor. Ketanserin and spiperone decreased the constitutive IP

stimulation by 80% and 58% respectively.

Several antipsychotic drugs presently in use are thought to act at the 5-HT_{2A} receptor. As shown in Figure 18, all these drugs, chlorpromazine, haloperidol, loxapine, clozapine, and risperidone as well as spiperone reduce the
5 constitutively activated IP basal activity of the mutated 5-HT_{2A} receptor.

The constitutively active ser → lys mutated 5-HT_{2C} receptor of this invention can also be used to screen compounds for inverse agonist activity. Figure 19 shows that two classical 5-HT_{2C} receptor antagonists, mianserin and mesulergine, exhibit inverse agonist activity by decreasing basal levels of PI
10 hydrolysis associated with the constitutively active 5-HT_{2C} mutant receptor. The inverse agonism of these compounds is apparent both in the presence and absence of serotonin.

The demonstration of inverse agonism at the mutated 5-HT_{2A} and 5-HT_{2C} receptors further characterizes the mutated serotonin receptors of this invention
15 as being constitutively active. Not only have the 5-HT_{2A} and 5-HT_{2C} receptors been mutated to a constitutively active form, but a method has been disclosed for mutating all mammalian G protein-coupled monoamine receptors, including serotonin receptors, to a constitutively active form. Unlike the case of the M5 muscarinic acetylcholine receptor where mutations in the third cytoplasmic loop
20 do not produce constitutive activation, the present invention clearly demonstrates that mutations in the third cytoplasmic loop of G protein-coupled serotonin receptors may be used to induce constitutive activation. Previously, third intracellular loop mutations near the transmembrane region had only been found to produce constitutively active receptors of the adrenergic type. With the present
25 discoveries, it is now recognized that the alignment and positional mutation method of this invention is applicable to the general class of monoamine receptors of which the adrenergic and serotonin receptors are major subclasses. Further, based upon the present discoveries, it is expected that mutations may be introduced at other sites in the third cytoplasmic loop which will constitutively
30 activate the G protein-coupled monoamine receptors including the serotonin receptors.

Additional Advances Enabled By The Discoveries Of The Present Invention:

Figures 20A and 20B show the DNA and amino acid sequences for the human 5-HT_{2A} receptors. In Figure 20A, it can be seen that the sixth transmembrane domain has the same WxPFFI conserved sequence (outlined type) as seen in the rat receptors. Figures 21A and 21B show the DNA and amino acid sequences for the human 5-HT_{2C} receptors. In Figure 21A it can be seen that the sixth transmembrane domain also has the same WxPFFI conserved sequence (outlined type) as seen in the rat receptors. Both of these human receptors may, therefore, be similarly aligned with the rat α 1-adrenergic, 5-HT_{2A}, and 5-HT_{2C} receptors to identify the amino acid positions which may be mutated to produce constitutively active human receptors following the methodologies of this invention.

Having identified mutations which constitutively activate the 5-HT_{2A} and 5-HT_{2C} serotonin receptors, it is now possible to create transgenic mammals incorporating these mutations using techniques well known in the art. This will provide an opportunity to study the physiological consequences of constitutive receptor activation and may lead to the development of novel therapeutic agents.

Those skilled in the art will recognize that various modifications, additions, substitutions and variations of the illustrative examples set forth herein can be made without departing from the spirit of the invention and are, therefore, considered within the scope of the invention.

References

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2. Kjelsberg, M., Cotecchia, S., Ostrowski, J. Caron, M. and Lefkowitz, R. (1992) *Constitutive Activation of the α_{1B} -Adrenergic Receptor by All Amino Acid Substitutions at a Single Site*. J. Biol. Chem. Vol. 267, 1430-1433
3. Samama, P., Cotecchia, S., Costa, T. and Lefkowitz, R. (1993) *A Mutation-induced Activated State of the B₂-Adrenergic Receptor*. J. Biol.

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4. Burstein, E., Spalding, T., Hill-Eubanks, D., & Brann, M. (1995) *Structure-Function of Muscarinic Receptor Coupling to G Proteins*. J. Biol. Chem. Vol 270, 3141-3146
- 5 5. The native rat 5-HT_{2A} receptor cDNA was generously donated by Dr. David Julius of the University of California, San Francisco.
6. The native rat 5HT_{2C} receptor cDNA was generously donated by Dr. Beth Hoffman of the National Institutes of Health.

CLAIMS

What is claimed is:

1. A method of constitutively activating targeted G protein-coupled mammalian monoamine receptors comprising the following steps:
 - 5 a. aligning a conserved amino acid sequence occurring in the sixth transmembrane domain of the targeted monoamine receptor with the conserved amino acid sequence in the sixth transmembrane domain of a second monoamine receptor for which a constitutively activated form having a mutation in the third intracellular loop is known;
 - 10 b. identifying in the aligned receptor sequences the amino acid position in the targeted monoamine receptor which corresponds to the amino acid position in the third intracellular loop which produced constitutive activation in the second monoamine receptor; and
 - 15 c. mutating, by site-directed mutagenesis, the identified amino acid position in the targeted monoamine receptor so that a different amino acid is substituted for the amino acid occurring in the native targeted receptor.
2. The method of claim 1 in which the targeted monoamine receptor is a G protein-coupled serotonin receptor.
- 20 3. The method of claim 2 in which the G protein-coupled serotonin receptor is the 5-HT_{2A} receptor.
4. The method of claim 2 in which the G protein-coupled serotonin receptor is the 5-HT_{2C} receptor.
5. The method of claim 1 in which the conserved amino acid sequence within
25 the sixth transmembrane domain used for the alignment is WxPFFI, where x represents that any amino acid may occur at that position.
6. A method of constitutively activating G protein-coupled mammalian serotonin receptors comprising the following steps:
 - 30 a. aligning a conserved amino acid sequence occurring in the sixth transmembrane domain of the serotonin receptor with the conserved amino acid sequence in the sixth transmembrane domain of the α_{1B} -adrenergic receptor for which a constitutively activated form having

- a mutation in the third intracellular loop is known;
- b. identifying in the aligned receptor sequences the amino acid position in the serotonin receptor which corresponds to the amino acid position in the third intracellular loop which produced constitutive activation in the α_{1B} -adrenergic receptor; and
- 5 c. mutating, by site-directed mutagenesis, the identified amino acid position in the serotonin receptor so that a different amino acid is substituted for the amino acid occurring in the native serotonin receptor.
- 10 7. The method of claim 6 in which the G protein-coupled serotonin receptor is the 5-HT_{2A} receptor.
8. The method of claim 6 in which the G protein-coupled serotonin receptor is the 5-HT_{2C} receptor.
9. The method of claim 6 in which the conserved amino acid sequence within
15 the sixth transmembrane domain used for the alignment is WxPFFI, where x represents that any amino acid may occur at that position.
10. The constitutively active 5-HT_{2A} receptor in which the amino acid at position number 322 has been mutated from the cysteine found in the native receptor to an amino acid selected from the group consisting of lysine, glutamic
20 acid, and arginine.
11. The constitutively active 5-HT_{2C} receptor in which the amino acid at position number 312 has been mutated from the serine found in the native receptor to an amino acid selected from the group consisting of lysine and phenylalanine.
- 25 12. The DNA encoding the constitutively active 5-HT_{2A} receptor in which the amino acid at position number 322 has been mutated from the cysteine found in the native receptor to an amino acid selected from the group consisting of lysine, glutamic acid, and arginine.
13. The DNA encoding the constitutively active 5-HT_{2C} receptor in which the
30 amino acid at position number 312 has been mutated from the serine found in the native receptor to an amino acid selected from the group consisting of lysine and phenylalanine.

14. A method of efficiently minimizing the number of full DNA sequencings, which must be performed on the colonies resulting from site-directed mutagenesis employing vectors, by eliminating most colonies not containing the desired mutation and by tagging colonies containing the desired mutation for easy

5 identification comprising the following steps:

- a. creating two primers, the first of which will remove a restriction site occurring in the original form of the vector and the second of which will introduce the desired mutation as well as a second mutation which specifies a unique restriction site not found in the primer;
- 10 b. annealing the primers to the vector;
- c. synthesizing the second strands;
- d. exposing the double stranded DNA to the restriction enzyme for the restriction site which occurs on the original vector thereby digesting the DNA containing the restriction site so that it cannot be taken up
- 15 during a subsequent transformation;
- e. transforming the test organism with the remaining double stranded circular DNA; and
- f. testing the resulting colonies to see if they contain DNA which can be digested by the restriction enzyme for the unique site introduced
- 20 by the second primer

whereby only DNA from those colonies which have incorporated the desired mutation will be digested with the restriction enzyme for the unique restriction site and the presence of such digestion indicates that that colony contains the desired mutation.

25 15. The method of claim 14 in which the following additional steps are performed after step e and before step f of claim 14:

- e'. repeating a restriction digest using the restriction enzyme for the restriction site which occurs on the original vector; and
- e''. transforming the test organism with the remaining double stranded
- 30 circular DNA.

16. The constitutively active 5-HT_{2A} receptor coded by the DNA sequence specified in Figure 24 which DNA also contains a mutation creating a unique

restriction site.

17. The constitutively active 5-HT_{2A} receptor coded by the DNA sequence specified in Figure 27 which DNA also contains a mutation creating a unique restriction site.

5 18. The constitutively active 5-HT_{2A} receptor coded by the DNA sequence specified in Figure 30 which DNA also contains a mutation creating a unique restriction site.

10 19. The constitutively active 5-HT_{2C} receptor coded by the DNA sequence specified in Figure 33 which DNA also contains a mutation creating a unique restriction site.

20. The constitutively active 5-HT_{2C} receptor coded by the DNA sequence specified in Figure 36 which DNA also contains a mutation creating a unique restriction site.

15 21. The use of the constitutively activated mammalian G protein-coupled monoamine receptor to screen for agonists, inverse agonists, and antagonists not previously identified as such at the native receptor.

22. The method of claim 21 where the mammalian G protein-coupled monoamine receptor is a serotonin receptor.

20 23. A transgenic mammal having incorporated and expressed in its genome a constitutively activated monoamine G protein-coupled receptor.

24. The transgenic mammal of claim 23 wherein the constitutively activated monoamine G protein-coupled receptor is a serotonin receptor.

25. The method of constitutively activating G protein-coupled receptors as described and illustrated in the specification.

25 26. The method of efficiently minimizing the number of full DNA sequencings as described and illustrated in the specification.

27. The constitutively activated receptors as described and illustrated in the specification.

30 28. DNA encoding constitutively activated receptors as described and illustrated in the specification.

29. The invention as described and illustrated in the specification.

Rat 5-HT_{2A}

1 cccaggctat gaacccttag tctctccaca cttcatctgc tacaacttcc ggcttagaca
61 tggaattct ttgtgaagac aatatctctc tgagctcaat tccaaactcc ttaatgcaat
121 taggtgatgg cccgaggctc taccataatg acttcaactc cagagatgct aacacttcgg
181 aagcatcgaa ctggacaatt gatgctgaaa acagaaccaa cctctcctgt gaagggtacc
241 tcccaccgac atgcctctcc attcttcac tccaggaaaa aaactggctc gctttattga
301 caactgtcgt gattattctc accattgctg gaaatatact ggtcatcatg gcagtgctcc
361 tagaaaaaaa gctgcagaat gccaccaact atttctgat gtcacttgcc atagctgata
421 tgctgctggg ttctctgtc atgcctgtgt ccatgttaac catcctgtat gggtagcggt
481 ggcctttgcc tagcaagctc tgtcgatct ggatttacct gcatgtgctc tttctacgg
541 catccatcat gcacctctgc gccatctccc tggaccgcta tgtcgccatc cagaacccca
601 ttcaccacag ccgcttcaac tccagaacca aagccttcct gaaaatcatt gccgtgtgga
661 ccatatctgt aggtatatcc atgccaatcc cagtctttgg actacaggat gattcgaagg
721 tctttaagga ggggagctgc ctgcttgccg atgacaactt tgttctcata ggctcttttg
781 tggcattttt catcccccta accatcatgg tgatcaccta ctctctgact atcaagtcac
841 ttcagaaaga agccaccttg tgtgtgagtg acctcagcac tcgagccaaa ctagcctcct
901 tcagcttcct cctcagagt tctctgtcat cagaaaagct cttccaacgg tccatccaca
961 gagagccagg ctctacgca ggccgaagga cgatgcagtc catcagcaat gagcaaaagg
1021 cgtgcaaggt gctgggcac gtgttcttcc tttttgtgt aatgtggtgc ccattcttca
1081 tcaccaatat catggccgtc atctgcaaag aatcctgcaa tgaaaatgtc atcggagccc
1141 tgctcaatgt gttgtcttg attggttacc tctcctcagc tgtaatcca ctggtatata
1201 cgttgttcaa taaaacttat aggtccgcct tctcaaggta cattcagtgt cagtacaagg
1261 aaaacagaaa gccactgcag ttaattttag tgaacactat accagcattg gcctacaagt

FIGURE 1A

1321 ctagtcagct ccaggtggga cagaaaaaga actcacagga agatgctgag cagacagtg
1381 atgactgctc catggttaca ctggggaaac aacagtcgga agagaattgt acagacaata
1441 ttgaaaccgt gaatgaaaag gttagctgtg tgtgatgaac tggatgctat ggcaattgcc
1501 cagggcatgt gaacaagggt ataccatgt gtgtggggcg gggataagga ggctgcaaca
1561 aattag

FIGURE 1A - CONTINUED

Rat 5-HT_{2A}

MEILCEDNISLSSIPNSLMQLGDGPRLYHNDNFNSRDANTSEASN
WTIDAENRTNLSCEGYLPPTCLSILHLQEKNEWSALLTTVVIILTIAGNILVIMAVSLE
KKLQNATNYFLMSLAIADMLLGFLVMPVSMLTILYGYRWPLPSKLCAIWIYLDVLFST
ASIMHLCAISLDRYVAIQNPIHHSRFSNRTKAFLKIIAVWTISVGISMPIPVFGLQDD
SKVFKEGSCLLADDNFVLIGSFVAFFIPLTIMVITYFLTIKSLQKEATLCVSDLSTRA
KLASFSFLPQSSLSSEKLFQRSIHREPGSYAGRRTMQSISNEQKACKVLGIVFFLFVV
MWCPFFITNIMAVICKESCNENVIGALLNVFVWIGYLSSAVNPLVYTFLFNKTYRSAFS
RYIQCOYKENRKPLQLILVNTIPALAYKSSQLQVGQKKNSQEDAEQTVDDCSMVTLGK
QQSEENCTDNIETVNEKVSCV

FIGURE 1B

Rat 5-HT_{2c}

ORIGIN 23 bp upstream of HindIII site.

1 ggcgctctgg tgctcactga ggaagcttcc ttaggtgtac cgatcttaat gattgagccc
61 ttggagcagc aagattgtta atcttggttg ctctttggc ctgtctatcc cttaccttcc
121 tattacatat gaacttttct tcgttctgca catcgattgt cgtcggcgtc gtggagatcg
181 tcgtggtgct ccggtggtgg tcttcgtccg cttagaatag ttagttagt taggggcctt
241 caaagaagaa agaagaagcg attggcgcg agagatgctg gaggtgtcag tttctatgct
301 agagtagggt agtgaaacaa tcccagcca aacctttccg gggggcgag gttgccaca
361 ggaggtegac ttgccggcgc tgccttcgc gccgagctcc ctccatcctt cttccgtct
421 gctgagacgc aaggttgcg cgcgacgct gagcagcgca ctgactgccg cgggctccgc
481 tgggcgattg cagccgagtc cgtttctcgt ctagctgccg ccgcggcgac ctgcctggtc
541 ttctcccgg acgctagcgg gttgtcaact attacctgca agcataggcc aacgaacacc
601 ttctttccaa attaattgga atgaacaat tctgttaact tcctaattct cagtttgaaa
661 ctctggttgc ttaagcctga agcaatcatg gtgaaccttg gcaacgcggt gcgctcgtc
721 ctgatgcacc taatcggcct attggttgg caattcgata tttccataag tccagtagca
781 gctatagtaa ctgacacttt taattcctcc gatggtggac gcttgtttca attcccggac
841 ggggtacaaa actggccagc actttcaatc gtcgtgatta taatcatgac aatagggggc
901 aacattcttg ttatcatggc agtaagcatg gagaagaaac tgcacaatgc aaccaattac
961 ttcttaatgt ccctagccat tgctgatatg ctggtgggac tacttgcac gccctgtcc
1021 ctgcttgcta ttctttatga ttatgtctgg cctttaccta gatatttgtg ccccgcttgg
1081 atttcactag atgtgctatt ttcaactgcg tccatcatgc acctctgcgc catatcgtc
1141 gaccggtatg tagcaatacg taatcctatt gagcatagcc ggttcaattc gcggactaag
1201 gccatcatga agattgccat cgtttgggca atatcaatag gagtttcagt tcctatccct

FIGURE 2A

1261 gtgattggac tgagggacga aagcaaatg ttctgaata acaccacgtg cgtgctcaat
1321 gaccccaact tegtctcat cgggtcctc gtggcattct tcatcccggt gacgattatg
1381 gtgatcacct acttcttaac gatctacgtc ctgcgccgtc aaactctgat gttacttcga
1441 ggtcacaccg aggaggaact ggctaataag agcctgaact ttctgaactg ctgctgcaag
1501 aagaatggtg gtgaggaaga gaacgctccg aaccctaate cagatcagaa accacgtcga
1561 aagaagaaag aaaagcgtcc cagaggcacc atgcaagcta tcaacaacga aaagaaagct
1621 tccaaagtc ttggcattgt attctttgtg ttctgatca tctggtcccc gttttcact
1681 accaatatcc tctcggttct ttgtgggaag gcctgtaacc aaaagctaatt ggagaagctt
1741 ctcaatgtgt ttgtgtgat tggctatgtg ttttcaggca tcaatcctct ggtgtacact
1801 ctctttaata aaatttaccg aagggtcttc tctaaatatt tgcgtgcga ttataagcca
1861 gacaaaaagc ctctgttcg acagattcct agggttactg ccaactgctt gtctgggagg
1921 gagctcaatg ttaacattta tcggcatacc aatgaacgtg tggctaggaa agctaattgac
1981 cctgagcctg gcatagagat gcaggtggag aacttagagc tgccagtcaa cccctctaatt
2041 gtggtcagcg agaggattag tagtgtgtaa gcgaagagca gcgcagactt cctacaggaa
2101 agttctgta ggaaagtcct cccaccccc cgtgatttc ctgtgaatca taactaatgt
2161 aatattgct gtgtgacaag acagtgttt tataaatagc ttgcaaccc tgtactttac
2221 atcatgctt aatagtgaga ttcggtg

FIGURE 2A - CONTINUED

Rat 5-HT_{2c}

MVNLGNAVRSLLMHLIGLLVWQFDISISPVA AIVTDTFNSSDGG
RLFQFPDGVQNWPAISIVV IIMTIGGNILVIMAVSMEKKLHNATNYFLMSLAIADML
VGLLVMPLSLLAILYDYVWPLPRYLCPVWISLDVLFSTASIMHLCAISLD RYVAIRNP
IEHSRFNSRTKAIMKIAIVWAISIGVSVPIPVIGLRDESKVFVNNTTCVLNDPNFVLI
GSFVAFFIPLTIMVITYFLT IYVLRRTLMLLRGHTEEELANMSLNFLNCCCKKNGGE
EENAPNPNPDQKPRRKKKEKRPRGTMQAINNEKKASKVLGIVFFVFLIMWCPFFITNI
LSVLCGKACNQKLMEKLLNVFVWIGYVCSGINPLVYT LFNKIYRRAFSKYLRC DYKPD
KKPPVRQIPRVAATALSGRELNVNIYRHTNERVARKANDPEPGIEMQVENLELPVNPS
NVVSERISSV

FIGURE 2B

Rat α_{1B} -adrenergic

MNPDLDTGHNTSAPAHWGELKDDNFTGPNQTSSNSTLPQLDVTR

AISVGLVLGAFILFAIVGNILVILSVACNRHLRTPNTNYFIVNLAIADLLLSFTVLPFS

ATLEV LGYWVLLSFFCDIWA AVDVLCCTASILSLCAISIDRYIGVRYSLQYPTLVTRR

KAILALLSVWVLSTVISIGPLLGWKEPAPNDDKECGVTEEPFYALFSSLG SFYIPLAV

ILVMYCRVYIVAKRTTKNLEAGVMKEMSNSKELTLRIHSKNFHEDTLSSTKAKGHNPR

SSIAVKLFKFSREKKA AKTLGIVVGMFILCWLPFFIALPLGSLFSTLKPPDAVFKVVF

WLG YFN SCLNPIIYPCSSKEFKRAFMRILGCQCRGGRRRRRRRRRLGACAYTYRPWTRG

GS LERSQSRKDSLDDSGSCMSGTQRTLPSASPSGYLGRGTQPPVELCAFEWKPGAL

LSLPEPPGRRGRLD SGPLFTFKLLGDPESPGTEGDTSNGGCDTTTDLANGQPGFKSNM

PLAPGHF

FIGURE 3A

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Rat α_{1B} -adrenergic

1 gggcggactt taaaatgaat cccgatctgg acaccggcca caacacatca gcacctgccc
61 actggggaga gttgaaagat gacaacttca ctggcccca ccagacctg agcaactcca
121 cactgcccc actggacgtc accagggcca tctctgtgg cctggtgctg ggcgccttca
181 tcctctttgc catcgtgggc aacatcttgg tcctctgtc ggtggcctgc aaccggcacc
241 tgcggacgcc caccaactac ttatcgtca acctggccat tctgacctg ctgttgagtt
301 tcacagtact gcccttctcc gctaccctag aagtgccttg ctactgggtg ctgttgagtt
361 tcttctgtga catctgggca gcggtagatg tctgtgctg tacggcctcc atcctgagcc
421 tatgtgcat ctccattgac cgctacattg ggtgcgata ctctctgcag taccacacgc
481 tggtcacccg caggaaggcc atcttggcgc tcctcagtgt gtgggtcttg tccacggtea
541 tcctcatcgg gcctctcctt gcatggaaa aacctgcgcc caatgatgac aaagaatgtg
601 gggtcaccca agaacccttc tacgccctct ttctctcctt gggctccttc tacatccgc
661 tcgcggatcat cctggtcatg tactgccggg tctacatcgt ggccaagagg accaccaaga
721 atctggagcc gggagtcatg aaggaaatgt ccaactccaa ggagctgacc ctgaggatcc
781 actccaagaa cttcatgag gacaccctca gcagtacca ggccaagggc cacaaccca
841 ggagttccat agctgtcaaa cttttaagt tctccaggga aaagaaagca gccaaaacct
901 tgggcattgt agtcggaatg ttcatttat gttggctccc cttcttcac gctctccgc
961 ttggctcctt gttctccacc cttaaagccc cggacgccgt gttcaaggtg gtgttctggc
1021 tgggctactt caacagctgc ctcaatccca tcctctacc gtgctccagc aaggagtta
1081 agcgcgcctt catgcgtatc cttgggtgcc agtgccgcgg tgccgcgcgc cgcgcgcgc
1141 gtcgcctct aggcgcgtgc gcttacacct accggccgtg gacccgcgcg ggtcgcctg
1201 agagatcaca gtcgcggaag gactctctg atgacagcg cagctgcag agcggcacgc
1261 agaggaccct gccctcggcg tcgccagcc cgggctacct ggtcagagga acgcagccac

FIGURE 3B

1321 ccgtggagct gtgcgccttc cccgagtga aaccggggc gctgctcagc ttgccagagc
1381 ctcctggccg ccgcgcccg ctcgactctg gcccactctt caccttcaag ctccctggcg
1441 atcctgagag cccgggaacc gaaggcgaca ccagcaacgg gggctgcgac accacgaccg
1501 acctggccaa cgggcagccc ggcttcaaga gcaacatgcc cctggcgccc gggcactttt
1561 aggtccctt ttcctctcc cctcaacac actcacat cggggtgggg gagaacacca
1621 tcgtaggggc gggagggcgc gtggggggag tgcagccct aggtagacac agggtcgaa
1681 ggggacaagg ggggaggggg gcggggagag gggcagctgc tttctggca ggggcatggg
1741 tgccaggtac agcgaagagc tgggctgagc atgctgagag cgtggggggc ccccctagt
1801 gttccgggac ttaagtctct ctctcttctc tctctgtata tacataaaat gagttcctct
1861 attcgtattt atctgtgggt acacgtgcgt gtgtctgttc ggtgtacgtg tgggctgcat
1921 ggggtgtgagt gtgaggcctg cccgcacgcg cgtgccgggg cagagcgagt gcgccccctg
1981 gtgacgtcca ggtgtgttgt ttgtctcttg actttgtacc tctcaagccc ctccctgttc
2041 tctagtcaat gctggcactt tgataggatc ggaaaacaag tcagatatta aagatcattt
2101 ctccctgtg

FIGURE 3B - CONTINUED

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<u>α_{1B}-adrenergic</u>	<u>5HT_{2A}</u>	<u>5HT_{2C}</u>
285 K	S	A
F	I 315	I 305
S	S	N
R	N	N
E	E	E
290 K	Q	K
K	K 320	K 310
A	A	A
293 A	C 322	S 312
K	K	K
295 T	V	V
L	L 325	L 315
G	G	G
I	I	I
V	V	V
300 V	F	F
G	F 330	F 320
M	L	V
F	F	F
I	V	L
305 L	V	I
C	M 335	M 325
W	W	W
L	C	C
P	P	P
310 F	F	F
F	F 340	F 330
I	I	I
A	T	T
L	N	N
315 P	I	I
L	M 345	L 335
G	A	S
S	V	V
319 L	I	L

↓
c-terminus

↖
Transmembrane
Domain VI

FIGURE 4

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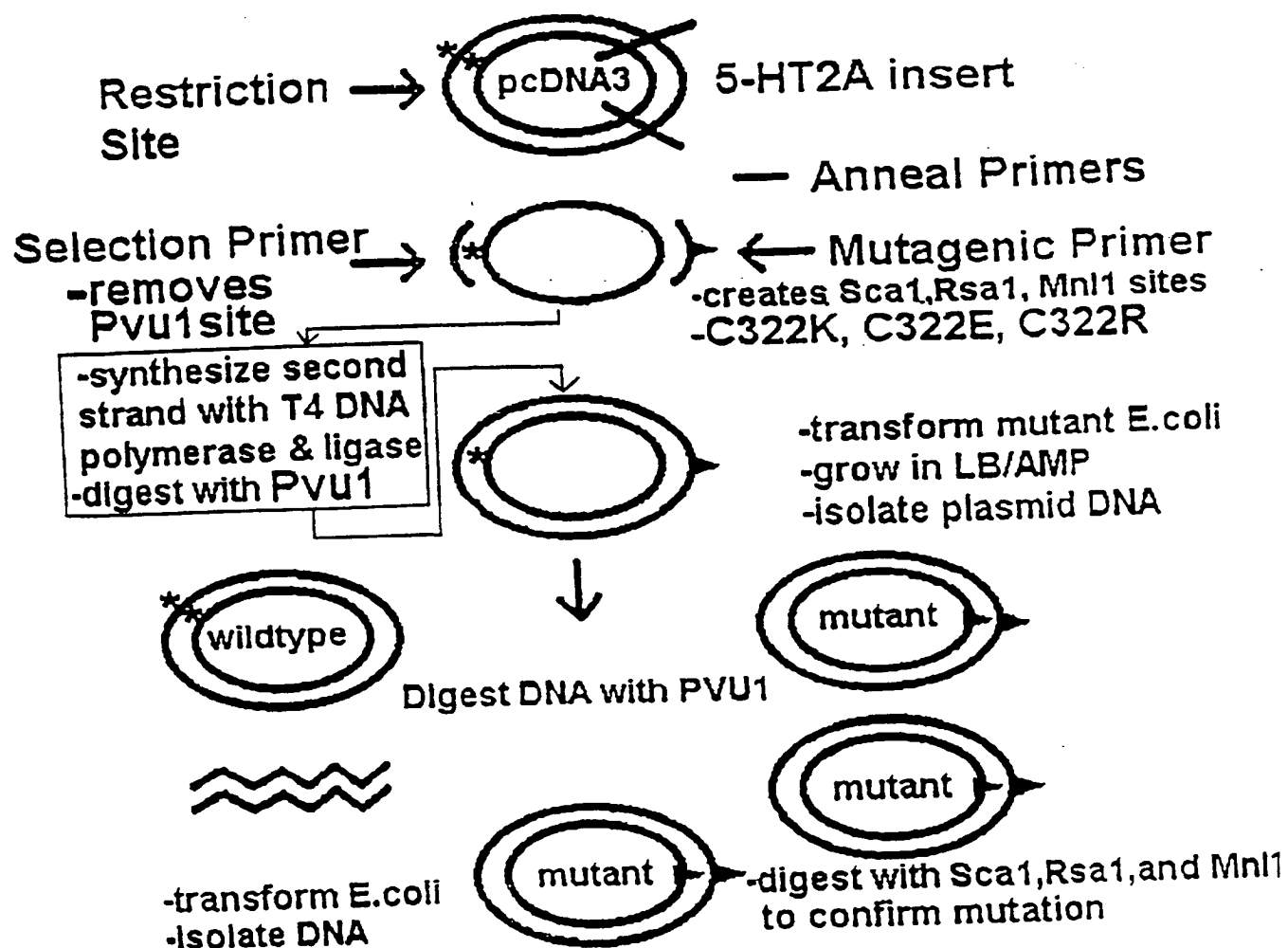


FIGURE 5

Site-direct. \downarrow mutagenesis procedure for the 5-HT_{2C} receptor.

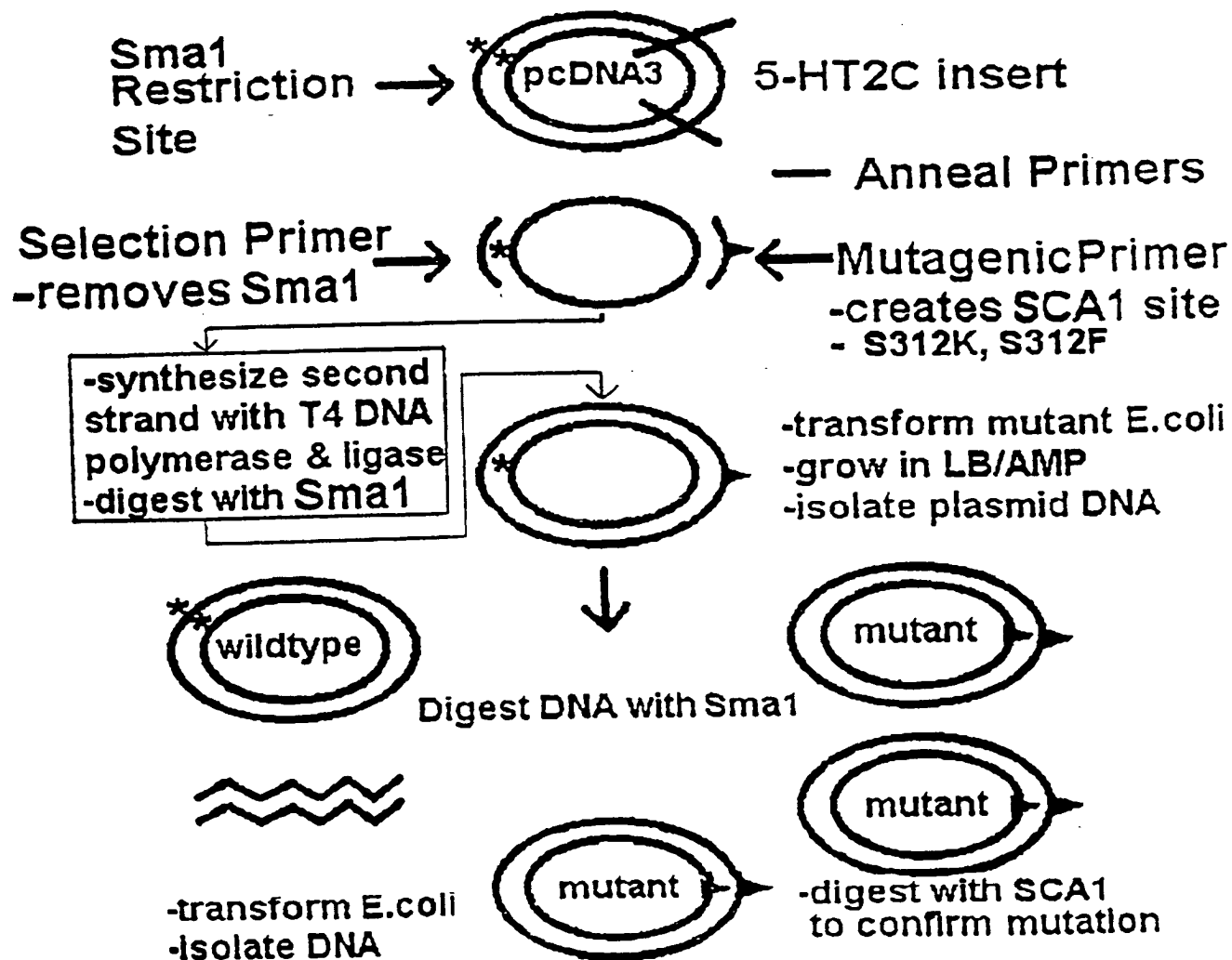


FIGURE 6

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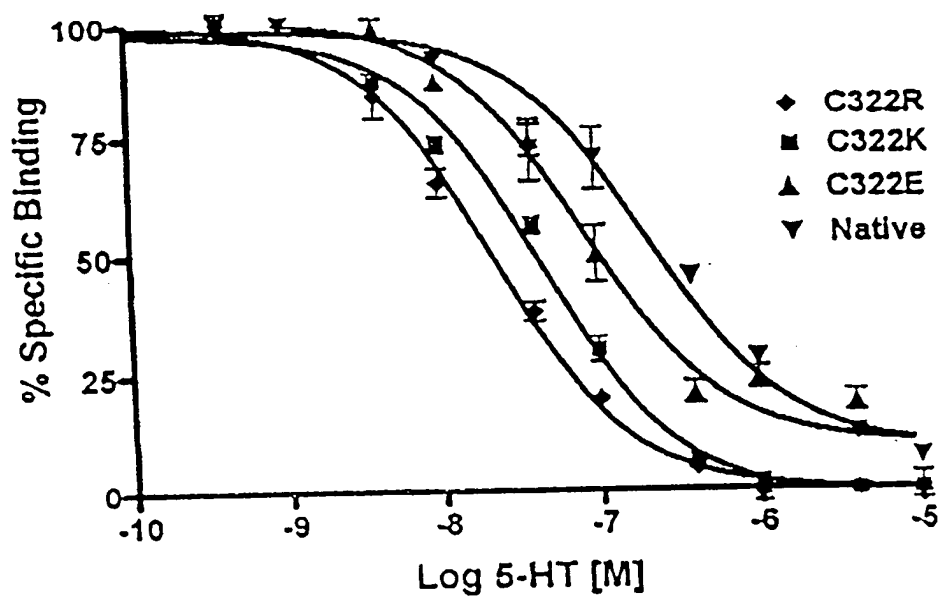


FIGURE 7

	Native 5-HT _{2A}	Cys→Lys Mutant	Cys→Arg Mutant	Cys→Glu Mutant
Agonists				
5-HT	293±3.0	25±2.1*	10±1.7	86±2.9
DOB	17±1.4	2.3±0.3*		
DOM	144±52	28±0.3*		
Antagonists				
Spiperone	1.1±0.1	2.4±1.0		
Methysergide	0.3±0.1	6.0±0.7*		
Ketanserin	1.0±0.3	1.0±0.1		
Mianserin	3.9±22	13±2.0*		

FIGURE 8



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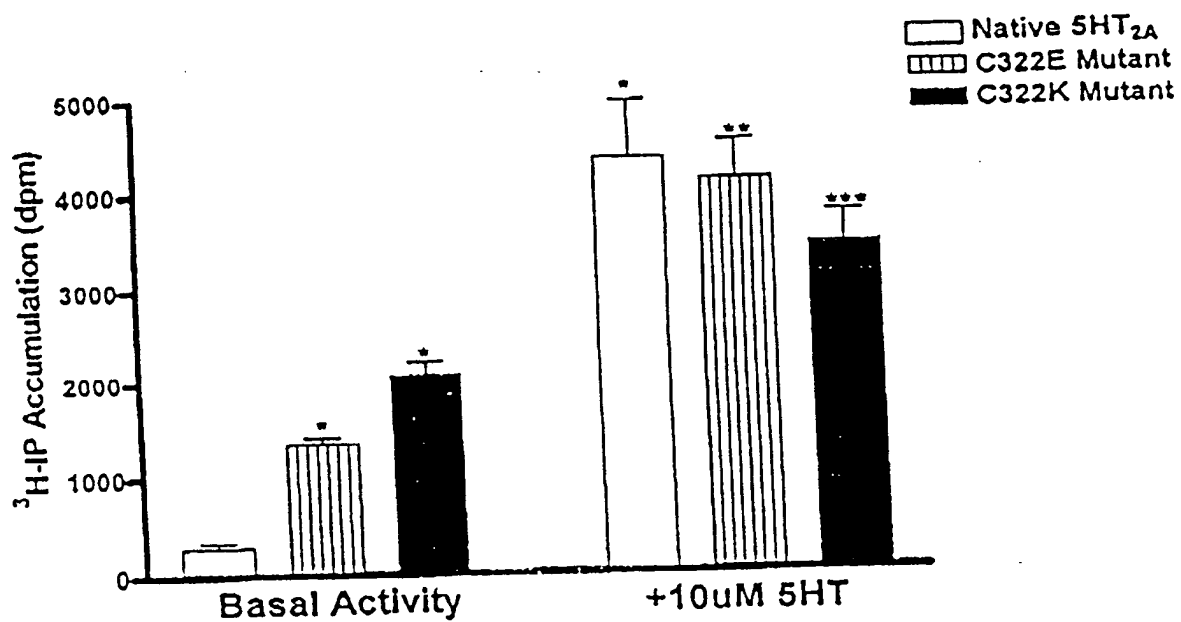


FIGURE 10

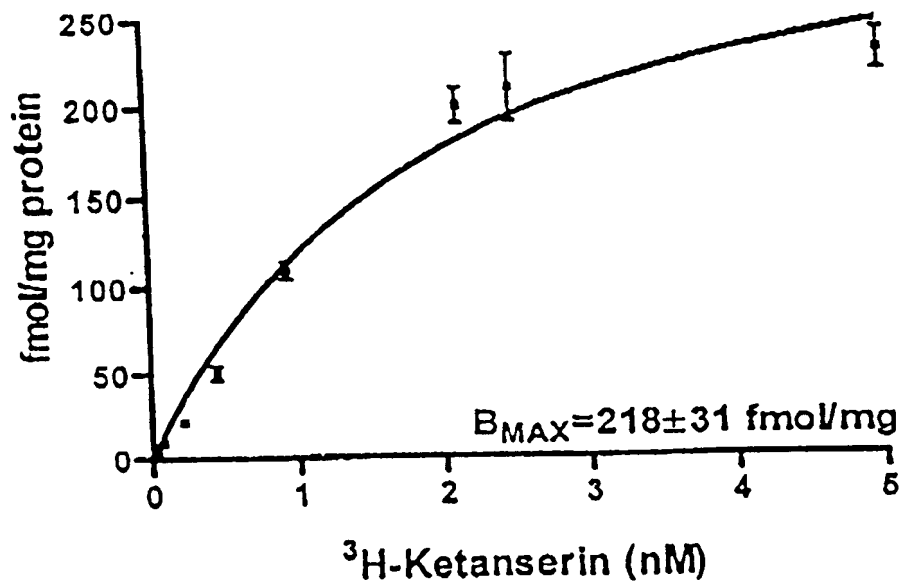
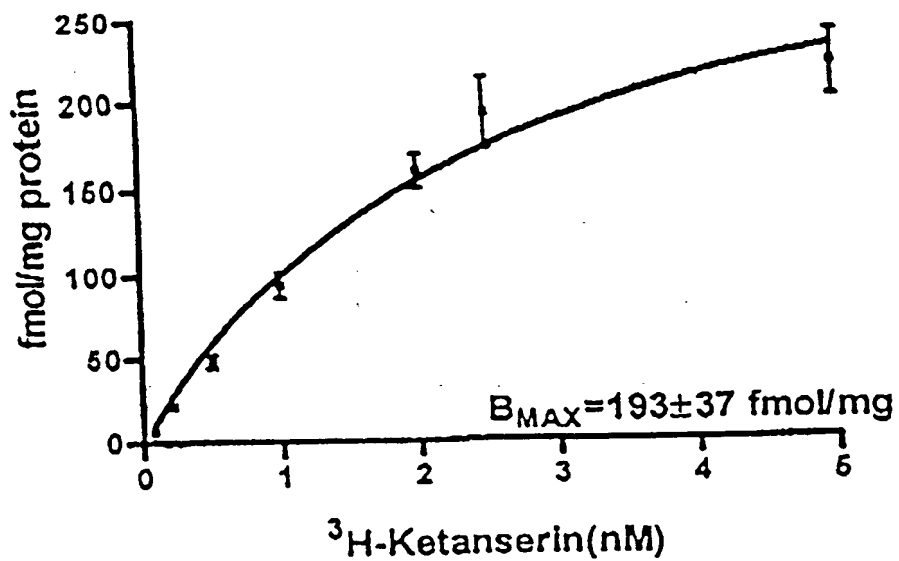


FIGURE 11

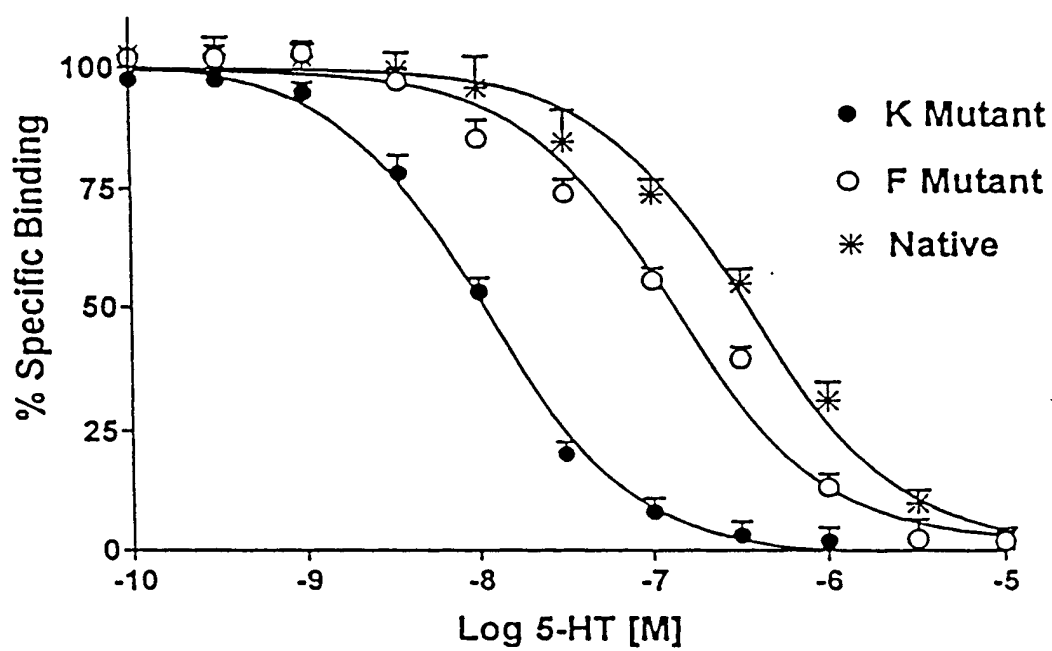


FIGURE 12

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K _i (nM)			
Agonists	Native	K Mutant	F Mutant
5-HT	203+/-10	6.6+/-1.2*	76+/-7.1*
5-MT	519+/-104	5.8+/-1.1*	ND
(+/-)DOB	256+/-38	6.7+/-0.7*	ND
Antagonists			
Mesulergine ^a	0.6+/-0.1	1.2+/-0.1*	1.3+/-0.2*
Mianserin	1.7+/-0.2	3.0+/-0.7**	ND
Methysergide	0.5+/-0.1	0.9+/-0.1**	ND

FIGURE 13

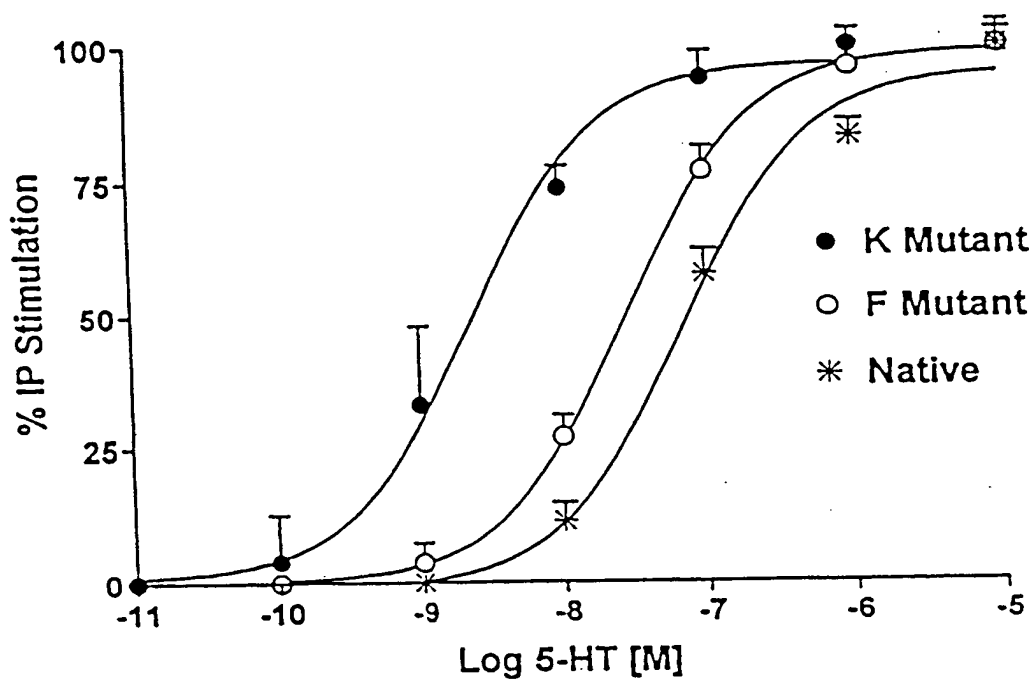


FIGURE 14

5-HT _{2c} Receptor	5-HT EC ₅₀ (nM)	K ₀ (nM)	Bmax (pm/mg)
Native	70+/-18	0.6+/-0.1	1.5+/-0.2
F Mutant	28+/-2.5*	1.3+/-0.2*	0.6+/-0.1*
K Mutant	2.7+/-1.1*	1.2+/-0.1*	1.4+/-0.2

FIGURE 15

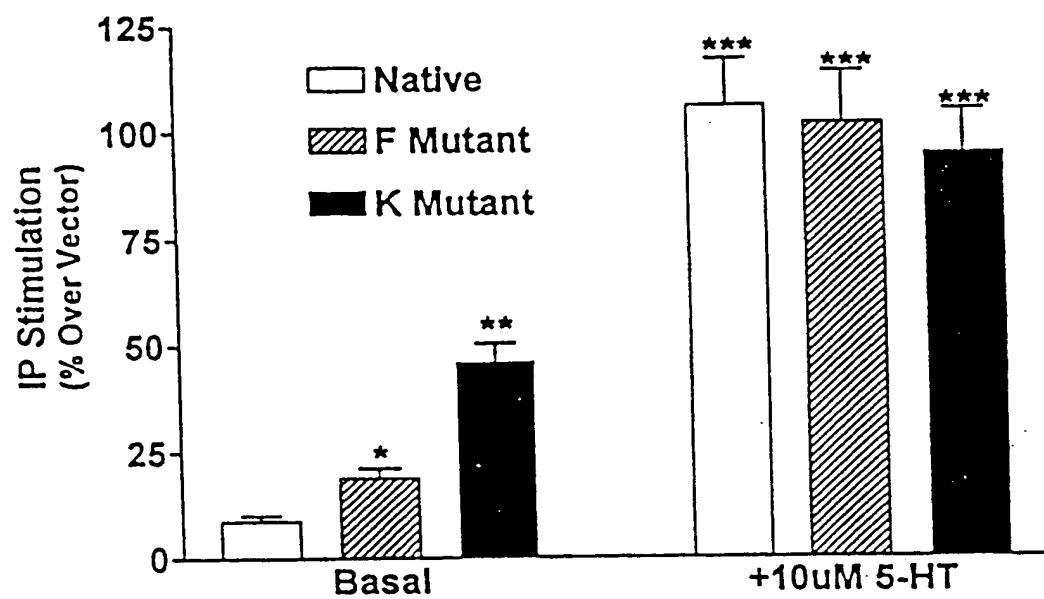


FIGURE 16

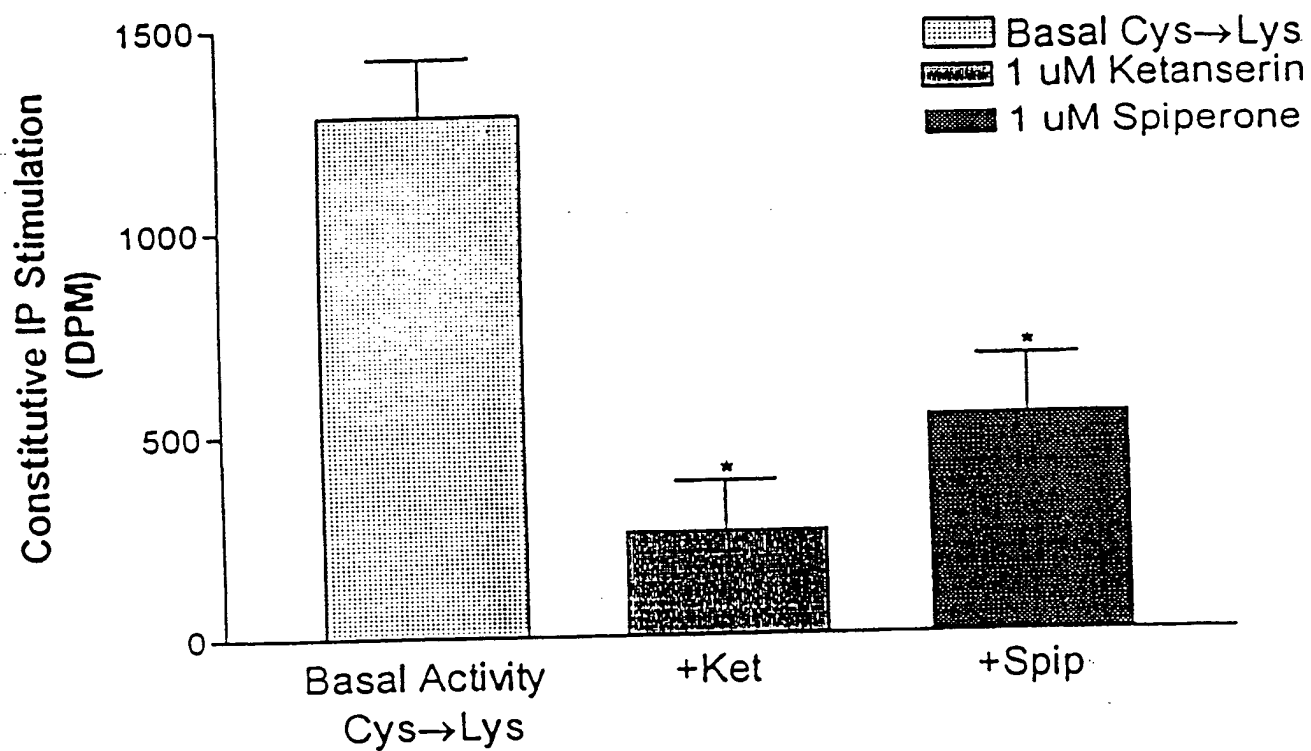


FIGURE 17

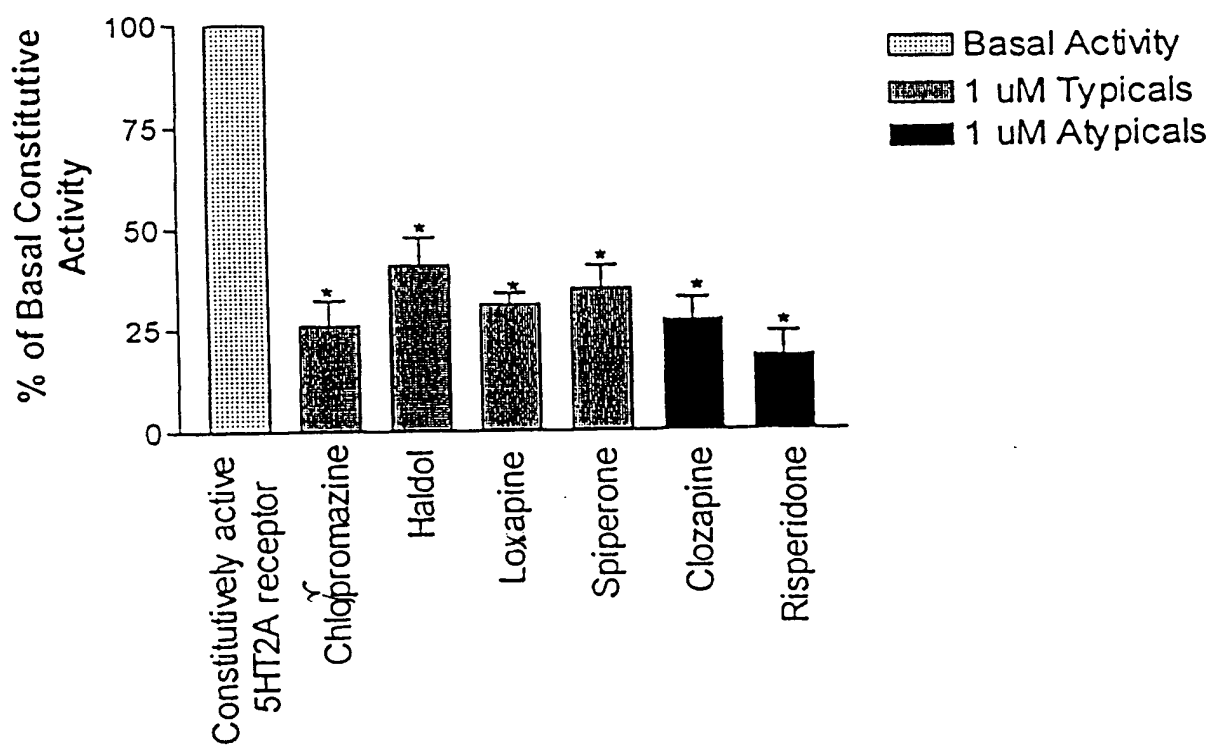


FIGURE 18

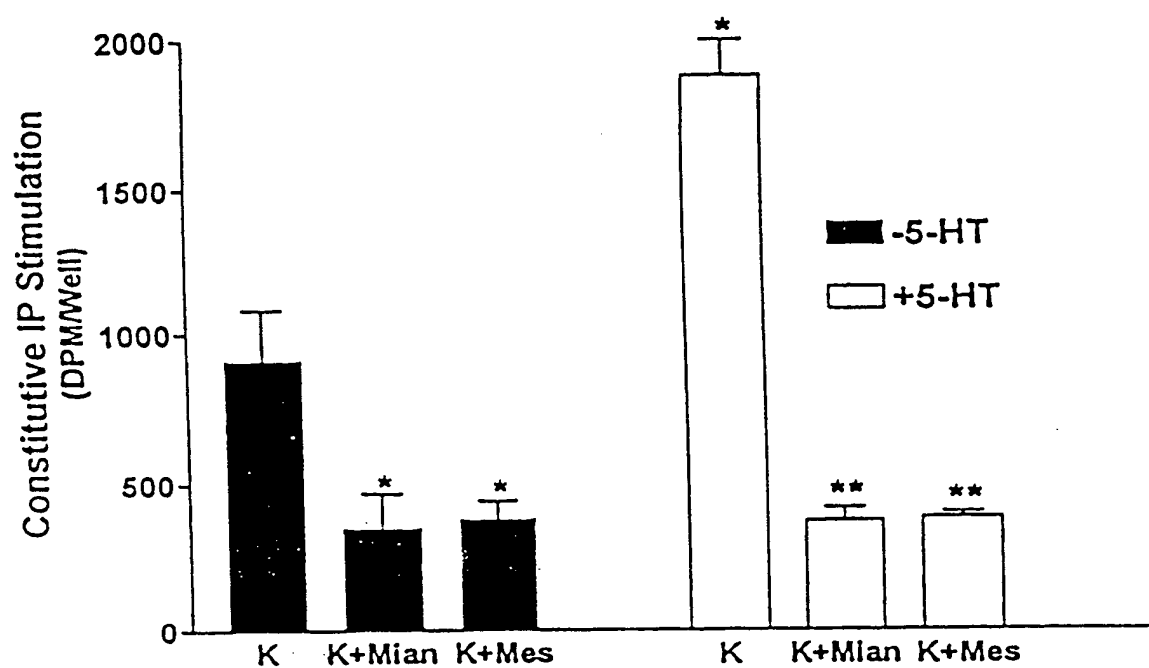


FIGURE 19

Human 5-HT_{2A}

1 gaattcgggt gagccagctc cgggagaaca gcatgtacac cagcctcagt gttacagagt
61 gtgggtacat caaggtgaat ggtgagcaga aactataacc tgtagtcct tctacacctc
121 atctgctaca agttctggct tagacatgga tattctttgt gaagaaaata cttctttgag
181 ctcaactacg aactccctaa tgcaattaaa tgatgacacc aggctctaca gtaatgactt
241 taactctgga gaagctaaca cttctgatgc atttaactgg acagtcgact ctgaaaaatc
301 aaccaacctt tcctgtgaag ggtgcctctc accgtcgtgt ctctccttac ttcattccca
361 ggaaaaaaac tggctcgtct tactgacagc cgtagtgtatt attctaacta ttgctggaaa
421 catactcgtc atcatggcag tctccctaga gaaaaagctg cagaatgccca ccaactattt
481 cctgatgtca cttgccatag ctgatatgct gctgggtttc cttgtcatgc ccgtgtccat
541 gttaaccatc ctgtatgggt accggtggcc tctgccgagc aagctttgtg cagtctgga
601 ttacctggac gtgctcttct ccacggcctc catcatgcac ctctgcgccca tctcgtgga
661 ccgctacgtc gccatccaga atcccatcca ccacagccgc ttcaactcca gaactaaggg
721 atttctgaaa atcattgctg tttggaccat atcagtaggt atatccatgc caataccagt
781 ctttgggcta caggacgatt cgaaggtctt taaggagggg agttgcttac tgcgccatga
841 taactttgtc ctgatcggt cttttgtgc attttcatt cccttaacca tcatggat
901 cacctacttt ctaactatca agtcactcca gaaagaagct actttgtgtg taagtatct
961 tggcacacgg gccaaattag cttctttcag ctctctcct cagagttctt tctcttcaga
1021 aaagctcttc cagcggtcga tccatagggg gccagggtcc tacacaggca ggaggactat
1081 gcagtcctac agcaatgagc aaaaggcatg caaggtgctg ggcacgtct tcttctgtt
1141 tgtggtgatg tgggtccctt tcttcacac aaacatcatg gccgtcatct gcaaagagtc
1201 ctgcaatgag gatgtcattg gggccctgct caatgtgtt gttggatcg gttatctctc
1261 ttcagcagtc aaccactag tctacacact gttaacaag acctataggt cagccttttc

FIGURE 20A

1321 acggtatatt cagtgtcagt acaaggaaaa caaaaaacca ttgcagttaa ttttagtgaa
1381 cacaataccg gctttggcct acaagtctag ccaacttcaa atgggacaaa aaaagaattc
1441 aaagcaagat gccagacaa cagataatga ctgctcaatg gttgctctag gaaagcagca
1501 ttctgaagag gcttctaaag acaatagcga cggagtgaat gaaaagggtga gctgtgtgtg
1561 ataggctagt tgccgtggca actgtggaag gcacactgag caagttttca cctatctgga
1621 aaaaaaaaaat atgagattgg aaaaaattag acaagtctag tggaaccaac gatcatatct
1681 gtatgcctca ttttattctg tcaatgaaaa gcgggggttca atgctacaaa atgtgtgctt
1741 ggaaaatgtt ctgacagcat ttcagctgtg agctttctga tacttattta taacattgta
1801 aatgatatgt ctttaaatg attcactttt attgtataat tatgaagccc taagtaaate
1861 taaattaact tctattttca agtggaacc ttgctgctat gctgttcatt gatgacatgg
1921 gattgagttg gttacctatt gccgtaaata aaaatagcta taaatagtgaa aaattttatt
1981 gaataaatg gcctcttaaa aattatcttt aaaacttact atggtatata ttttgaaagg
2041 agaaaaaaaa aaagccacta aggtcagtgt tataaatct gtattgctaa gataattaa
2101 tgaaatactt gacaacattt ttcataagata ccattttgaa atattcaciaa ggttgctggc
2161 atttgctgca tttcaagta attctcagaa gtgaaaaaga ctcaaatgt tattcaataa
2221 ctattgctgc tttctcttct acttctgtg ctttactctg aatttcaggt gtggtctgt
2281 ttaatatttg ttctctagg taaactagca aaaggatgat ttaacattac caaatgcctt
2341 tctagcaatt gcttctctaa aacagcacta tcgaggtatt tggtaacttg ctgtgaaatg
2401 actgcatcat gcatgcactc ttttgagcag taaatgtata ttgatgtaac tgtgtcagga
2461 ttgaggatga actcaggttt ccggctactg acagtggtag agtcctagga catctctgta
2521 aaaagcaggt gactttccta tgacactcat caggtaaact gatgctttca gatccatcgg
2581 ttatactat ttattaaaac cattctgctt ggtccacaa tcatctattg agtgtacatt
2641 tatgtgtgaa gcaaatttct agatatgaga aatataaaaa taattaaaac aaaatccttg

FIGURE 20A - CONTINUED

2 8/58

2701 ccttcaaacg aaatggctcg gccaggcacg gaggctcgtg catgtaatcc tagcactttg
2761 ggaggctgag atgggaggat cacttgaggc caagagtttg agaccaacct gggtáacaaa
2821 gtgagacctc cctgtctcta caaaaaaat caaaaaatta tctgacctt gtggcacaca
2881 actgtggtcc cagctacagg ggaggctgag acgcaaggat cacttgagcc cagaagctca
2941 aggctgcagt gagccaagtt cacaccactg ccatttcctc ctgggcaaca gagtgagacc
3001 ctatcacccc gaattc

FIGURE 20A - CONTINUED

Human 5-HT2A

MDILCEENTSLSSTTNSLMQLNDDTRLYSNDFNSGEANTSDAFN
WTVDSERNTNLSCEGCLSPSCLSLHLQEKNEWSALLTAVVIILTIAGNILVIMAVSLE
KKLQONATNYFLMSLAIADMLLGFLVMPVSMILTILYGYRWPLPSKLCVWYLDVLFST
ASIMHLCAISLDTRYVAIQNPIHHSRFRNSRTKAFLKIIAVWTISVGISMPIPVFGLQDD
SKVFKEGSCLLADDNFVLIGSFVSFFIPLTIMVITYFLTIKSLQKEATLCVSDLGTRA
KLASFSFLPQSSLSSEKLFQRSIHREPGSYTGRRMQSISNEQKACKVLGIVFFLFVV
MWCPFFITNIMAVICKESCNEVDIGALLNVFVWIGYLSSAVNPLVYTLFNKTYRSAFS
RYIQCQYKENKKPLQLILVNTIPALAYKSSQLQMGQKNSKQDAKTTDNDCSMVALGK
QHSEEASKDNSDGVNEKVSCV

FIGURE 20B

Human 5-HT_{2c}

1 gaattcggga gcgtcctcag atgcaccgat ctccccgata ctgcctttgg agcgggctaga
61 ttgctagcct tggctgctcc attggcctgc cttgcccctt acctgccgat tgcataatgaa
121 ctctttcttct gtctgtacat cgttgctgctc ggagtcgctc cgatcgtcgt ggcgctcgtg
181 tgatggcctt cgtccgttta gagtagtgta gttagttagg ggccaacgaa gaagaaagaa
241 gacgcgatta gtgcagagat gctggagggtg gtcagttact aagctagagt aagatagcgg
301 agcgaaaaga gccaaaccta gccggggggc gcacggtcac ccaaaggagg tcgactcgcc
361 ggcgcttctt atcgcgccga gctccctcca ttctctccc tccgccgagg cgcgagggtg
421 cggcgcgag cgcagcgag ctacgagcac cgactgccgc gggctccgct gggcgattgc
481 agccgagtcc gtttctgctc tagctgccgc cgcggcgacc gctgcctggt cttctccccg
541 gacgctagtg ggttatcagc taacaccgc gagcatctat aacataggcc aactgacgcc
601 atccttcaaa aacaactgtc tgggaaaaaa agaataaaaa gtagtgtgag agcagaaaac
661 gtgattgaaa cacgaccaat ctttcttcag tgccaaaggg tggaaaagaa aggatgatat
721 gatgaaccta gcctgttaat ttctgttct caattttaa ctttggttgc ttaagactga
781 agcaatcatg gtgaacctga ggaatgcgtt gcattcattc cttgtgcacc taattggcct
841 attggtttgg caatgtgata tttctgtgag cccagtagca gctatagtaa ctgacatttt
901 caatacctcc gatggtggac gcttcaaatt cccagacggg gtacaaaact ggccagcact
961 ttcaatcgtc atcataataa tcatgacaat aggtggcaac atccttgtga tcatggcagt
1021 aagcatggaa aagaaactgc acaatgccac caattacttc ttaatgtccc tagccattgc
1081 tcatatgcta gtgggactac ttgtcatgcc cctgtctctc ctggcaatcc tttatgatta
1141 tgtctggcca ctacctagat atttgtccc cgtctggatt tctttagatg tttattttc
1201 aacagcgtcc atcatgcacc tctgcgctat atcgttggat cggtatgtag caatacgtaa
1261 tcctattgag catagccgtt tcaattcgcg gactaaggcc atcatgaaga ttgctattgt

FIGURE 21A

1321 ttgggcaatt tctataggtg tatcagttcc tatccctgtg attggactga gggacgaaga
1381 aaaggtgttc gtgaacaaca cgacgtgcgt gctcaacgac ccaaatttcg ttcttattgg
1441 gtccttcgta gctttcttca taccgctgac gattatgggtg attacgtatt gcctgaccat
1501 ctacgttctg cggcgacaag ctttgatgtt actgcacggc cacaccgagg aaccgcctgg
1561 actaagtctg gatttcctga agtgctgcaa gaggaatacg gccgaggaag agaactctgc
1621 aaaccctaac caagaccaga acgcacgccc aagaaagaag aaggagagac gtcctagggg
1681 caccatgcag gctatcaaca atgaaagaaa agcttcgaaa gtccttgga ttgtttctt
1741 tggtttctg atcatgtgtt gcccatTTTT cattaccaat attctgtctg ttctttgtga
1801 gaagtcctgt aacaaaaagc tcatggaaaa gcttctgaat gtgtttgttt ggattggcta
1861 tggtttgttca ggaatcaatc ctctgggtga tactctgttc aacaaaattt accgaagggc
1921 attctccaac tatttgcgtt gcaattataa ggtagagaaa aagcctcctg tcaggcagat
1981 tccaagagtt gccgccactg ctttgtctgg gagggagctt aatgttaaca ttatcggca
2041 taccaatgaa ccggtgatcg agaaagccag tgacaatgag cccggtatag agatgcaagt
2101 tgagaattta gagttaccag taaatccctc cagtgtggtt agcgaaagga ttgacagtgt
2161 gtgagaaaga acagcacagt cttttctacg gtacaagcta catatgtagg aaaattttct
2221 tctttaattt ttctgttggc cttactaat gtaaatttg ctgtctgaaa aagtgtttt
2281 acatatagct ttgcaacctt gtactttaca atcatgccta cattagttag atttagggtt
2341 ctatatttac tgtttataat aggtggagac taactattt tgattgtttg atgaataaaa
2401 tgtttatTTT tgcctccct ccttcttct cttcctttt tctttcttc cttcctttct
2461 ctctttcttt tgtgcatatg gcaacgttca tgttcatctc aggtggcatt tgcaggtgac
2521 cagaatgagg cacatgacag tggttatatt tcaaccacac ctaaattaac aaattcagt
2581 gacatttggt ctgggttaac agtaaataa cactttacat tcttgctctg ctcatctaca
2641 catataaaca cagtaagata ggttctgctt tctgatacat ctgtcagtga gtcagaggca

FIGURE 21A - CONTINUED

2701 gaacctagtc ttgttgttca tataggggaa ttc

FIGURE 21A - CONTINUED

Human 5-HT_{2c}

MVNLRNAVHSFLVHLIGLLVWQCDISVSPVAAIVTDIFNTSDGG
RFKFPDGVQNWPAISIVIIIIMTIGGNILVIMAVSMEKKLHNATNYFLMSLAIADMLV
GLLVMPLSLLAILYDYVWPLPRYLCPVWISLDVLFSTASIMHLCAISLDRYVAIRNPI
EHSRFNSRTKAIMKIAIVWAISIGVSVPIPVIGLRDEEKVFNNTTCVLNDPNFVLIG
SFVAFFIPLTIMVITYCLTIYVLRQALMLLHGHTTEPPGLSLDFLKCKRNTAEEEN
SANPNQDQNARRRKKKERRPRGTMQAINNERKASKVLGIVFFVFLIMWCPFFITNILS
VLCEKSCNQKLMEKLLNVFVWIGYVCSGINPLVYTLFNKIYRRAFSNYLRCNYKVEKK
PPVRQIPRVAATALSGRELVNIYRHTNEPVIEKASDNEPGIEMQVENLELPVNPSSV
VSEISSV

FIGURE 21B

Rat 5-HT_{2A} Cysteine → Lysine Mutant

MEILCEDNISLSSIPNSLMQLGDGPRLYHNDNFNSRDANTSEASN

WTIDAENRTNLSCEGYLPPTCLSILHLQEKNEWSALLTTVVIIILTIAGNILVIMAVSLE

KKLQONATNYFLMSLAIDMLLGFLVMPVSMILTILYGYRWPLPSKLCAIWIYLDVLFST

ASIMHLCAISLDTRYVAIQNPPIHHSRFSRRTKAFLKIIAVWTISVGISMPIPVFGLQDD

SKVFKEGSCLLADDNFVLIGSFVAFFIPLTIMVITYFLTIKSLQKEATLCVSDLSTRA

KLASFSFLPOSSLSEKLFQRSIHREPGSYAGRRTMQSISNEQKA~~K~~KVLGIVFFLFVV

MWCPFFITNIMAVICKESCNENVIGALLNVFVWIGYLSSAVNPLVYTLENKTYRSAFS

RYIQCCQYKENRKPLQLILVNTIPALAYKSSQLQVGQKNSQEDAEQTVDDCSMVTLGK

QQSEENCTDNIETVNEKVSCV

FIGURE 22

Rat 5HT_{2A} Cysteine → Lysine Mutant

1 cccaggctat gaacccttag tctctccaca cttcatctgc tacaacttcc ggcttagaca
61 tgaaaattct ttgtgaagac aatatctctc tgagctcaat tccaaactcc ttaatgcaat
121 taggtgatgg cccgaggctc taccataatg acttcaactc cagagatgct aacacttcgg
181 aagcatcgaa ctggacaatt gatgctgaaa acagaaccaa cctctcctgt gaagggtacc
241 tcccaccgac atgcctctcc attcttcac cccaggaaaa aaactggctc gctttattga
301 caactgtcgt gattattctc accattgctg gaaatatact ggtcatcatg gcagtgtccc
361 tagaaaaaaa gctgcagaat gccaccaact atttctgat gtcacttgcc atagctgata
421 tgctgctggg ttcccttgct atgcctgtgt ccatgttaac catcctgtat gggtagccgt
481 ggcctttgcc tagcaagctc tgtcgatct ggatttacct ggaatgtctc tttctacgg
541 catccatcat gcacctctgc gccatctccc tggaccgcta tgtcgccatc cagaacccca
601 ttcaccacag ccgcttcaac tccagaacca aagccttcct gaaaatcatt gccgtgtgga
661 ccatatctgt aggtatatcc atgccaatcc cagtctttgg actacaggat gattcgaagg
721 tctttaagga ggggagctgc ctgcttgccg atgacaactt tgttctcata ggctcttttg
781 tggcattttt catcccccta accatcatgg tgatcaccta cttcctgact atcaagtcac
841 ttcagaaaga agccaccttg tgtgtgagtg acctcagcac tcgagccaaa ctagcctcct
901 tcagcttcct cctcagagt tctctgtcat cagaaaagct cttccaacgg tccatccaca
961 gagagccagg ctctacgca ggccgaagga cgaatgcagtc catcagcaat gagcaaaagg
1021 cgaa@aaaggt gctgggcac gtgttcttc tgtttgtgt aatgtggtgc ccattcttca
1081 tcaccaatat catggccgct atctgcaaag aatcctgcaa tgaaaatgct atcggagccc
1141 tgctcaatgt gttgtctgg attggttacc tctctcagc tgtcaatcca ctggtatata
1201 cgttgttcaa taaaacttat aggtccgcct tctcaaggta cattcaggt cagtacaagg
1261 aaaacagaaa gccactgcag ttaattttag tgaacactat accagcattg gcctacaagt

Start C322K primer →

← End C322K primer

FIGURE 23

1321 ctagtcagct ccaggtggga cagaaaaaga actcacagga agatgctgag cagacagttg
1381 atgactgctc catggttaca ctggggaaac aacagtcgga agagaattgt acagacaata
1441 ttgaaaccgt gaatgaaaag gttagctgtg tgtgatgaac tggatgctat ggcaattgcc
1501 cagggcatgt gaacaagggt atacccatgt gtgtggggcg gggataagga ggctgcaaca
1561 aattag

FIGURE 23 - CONTINUED

Rat 5HT_{2A} Cysteine → Lysine Mutant with Restriction Site

1 cccaggctat gaacccttag tctctccaca cttcatctgc tacaacttcc ggcttagaca
 61 tggaaattct ttgtgaagac aatatctctc tgagctcaat tccaaactcc ttaatgcaat
 121 taggtgatgg cccgaggctc taccataatg acttcaactc cagagatgct aacacttcgg
 181 aagcatcgaa ctggacaatt gatgctgaaa acagaaccaa cctctcctgt gaagggtacc
 241 tcccaccgac atgcctctcc attcttcac tccaggaaaa aaactgggtct gctttattga
 301 caactgtcgt gattattctc accattgctg gaaatatact ggtcatcatg gcagtgctcc
 361 tagaaaaaaa gctgcagaat gccaccaact atttctgat gtcacttgcc atagctgata
 421 tgctgctggg ttctcttgtc atgcctgtgt ccatgttaac catcctgtat gggtagcgtt
 481 ggcctttgcc tagcaagctc tgtgcgatct ggaattacct ggaatgtctc tttctacgg
 541 catccatcat gcacctctgc gccatctccc tggaccgcta tgcgccatc cagaacccca
 601 ttcaccacag ccgcttcaac tccagaacca aagccttctt gaaaatcatt gccgtgtgga
 661 ccatatctgt aggtatatcc atgccaatcc cagtctttgg actacaggat gattcgaagg
 721 tctttaagga ggggagctgc ctgcttgccg atgacaactt tgttctcata ggctcttttg
 781 tggcattttt catcccccta accatcatgg tgatcaccta cttcctgact atcaagtcac
 841 ttcagaaaga agccaccttg tgtgtgagt acctcagcac tcgagccaaa ctaggctcct
 901 tcagcttctt cctcagagt tctctgtcat cagaaaagct cttccaacgg tccatccaca
 961 gagagccagg ctctacgca ggccgaagga cgaatcagtc catcagcaat gagcaaaagg
 1021 cgaaagaaagt actgggcatc gtgtcttcc tgtttgtgt aatgtggtgc ccattctca
 1081 tcaccaatat catggccgtc atctgcaaag aatcctgcaa tgaatatgtc atcggagccc
 1141 tgtcaatgt gttgtctgg attggtatc tctcctcagc tgtcaatcca ctggtatata
 1201 cgttgttcaa taaaacttat aggtccgctt tctcaaggta cattcagtgt cagtacaagg
 1261 aaaacagaaa gccactgcag ttaattttag tgaacactat accagcattg gcctacaagt

Start C322K primer →
 End C322K primer ←
 ↑ ↑ Mutations to create ScaI site

FIGURE 24

1321 ctagtcagct ccaggtggga cagaaaaaga actcacagga agatgctgag cagacagttg
1381 atgactgctc catggttaca ctggggaaac aacagtcgga agagaattgt acagacaata
1441 ttgaaaccgt gaatgaaaag gttagctgtg tgtgatgaac tggatgctat ggcaattgcc
1501 cagggcatgt gaacaagggt atacccatgt gtgtggggcg gggataagga ggctgcaaca
1561 aattag

FIGURE 24 - CONTINUED

Rat 5-HT_{2A} Cysteine → Arginine Mutant

MEILCEDNISLSSIPNSLMQLGDGPRLYHNDFNSRDANTSEASN
WTIDAENRTNLSCEGYLPPTCLSILHLQEKNEWSALLTTVVIILTIAGNILVIMAVSLE
KKLQNAATNYFLMSLAIDMMLLGFLVMPVSMILTILYGYRWPLPSKLCAlWIYLDVLFST
ASIMHLCAISLDYVAIQNPiHHSRfNSRTKAFLKIIAVWTISVGISMPIPVFGLQDD
SKVFKEGSCLLADDNFVLIGSFVAFFIPLTIMVITYFLTIKSLQKEATLCVSDLSTRA
KLASFSFLPQSSLSSEKLFQRSIHREPGSYAGRRTMQSISNEQKA^RKVLGIVFFLFVV
MWCPFFITNIMAVICKESCNENVIGALLNVFVWIGYLSSAVNPLVYTLFNKTYRSAFS
RYIQCQYKENRKPLQLILVNTIPALAYKSSQLQVGQKNSQEDAEQTVDDCSMVTLGK
QQSEENCTDNIETVNEKVSCV

FIGURE 25

Rat 5HT_{2A} Cysteine → Arginine Mutant

1 cccaggctat gaacccttag tctctccaca cttcatctgc tacaacttcc ggcttagaca
61 tggaattct ttgtgaagac aatatctctc tgagctcaat tccaaactcc ttaatgcaat
121 taggtgatgg cccgaggctc taccataatg acttcaactc cagagatgct aacacttcgg
181 aagcatcgaa ctggacaatt gatgctgaaa acagaaccaa cctctcctgt gaagggtacc
241 tcccaccgac atgcctctcc attcttcac tccaggaaaa aaactgggtct gctttattga
301 caactgtcgt gattattctc accattgctg gaaatatact ggtcatcatg gcagtgcccc
361 tagaaaaaaa gctgcagaat gccaccaact atttctgat gtcacttgcc atagctgata
421 tgctgctggg tttccttgc atgcctgtgt ccatgttaac catcctgtat gggtagccgt
481 ggcctttgcc tagcaagctc tgtgcgatct ggatttacct ggatgtgctc tttctacgg
541 catccatcat gcacctctgc gccatctccc tggaccgcta tctgccatc cagaacccca
601 ttcaccacag ccgcttcaac tccagaacca aagccttctt gaaaatcatt gccgtgtgga
661 ccatatctgt aggtatatcc atgccaatcc cagtctttgg actacaggat gattcgaagg
721 tctttaagga ggggagctgc ctgcttgccg atgacaactt ttttctcata ggctcttttg
781 tggcattttt catcccccta accatcatgg tgatcaccta cttctgact atcaagtcac
841 ttcagaaaga agccaccttg tgtgtgagt acctcagcac tggagccaaa ctgacctctt
901 tcagcttctt ccctcagagt tctctgtcat cagaaaaagt cttccaacgg tccatccaca
961 gagagccagg ctctacgca gcccgaagga cgatgcagtc catcagcaat gagcaaaagg
1021 cgaggaaggt gctgggcac gtgttcttc tgtttgtgt aatgtggtgc ccattcttca
1081 tcaccaatat catggccgtc atctgcaaag aatcctgcaa tgaaaatgtc atcggagccc
1141 tgctcaatgt gttgtctgg attggttatc tctcctcagc tgtcaatcca ctggtatata
1201 cggtgttcaa taaaacttat aggtccgcct tctcaaggta cattcagtt cagtacaagg
1261 aaaacagaaa gccactgcag ttaattttag tgaacactat accagcattg gcctacaagt

Start C322R primer

End C322R primer

FIGURE 26

1321 ctagtcagct ccaggtggga cagaaaaaga actcacaaga agatgctgag cagacagttg
1381 atgactgctc catggttaca ctggggaaac aacagtcgga agagaattgt acagacaata
1441 ttgaaaccgt gaatgaaaag gttagctgtg tgtgatgaac tggatgctat ggcaattgcc
1501 cagggcatgt gaacaagggt atacccatgt gtgtggggcg gggataagga ggctgcaaca
1561 aattag

FIGURE 26 - CONTINUED

Rat 5HT_{2A} Cysteine → Arginine Mutant with Restriction Site

1 cccaggctat gaaccctag tctctccaca cttcatctgc tacaactcc ggcttagaca
61 tggaattct ttgtgaagac aatattcttc tgagctcaat tccaaactcc ttaatgcaat
121 taggtgatgg cccgaggctc taccataatg acttcaactc cagagatgct aacacttcgg
181 aagcatcgaa ctggacaatt gatgctgaaa acagaaccaa cctctcctgt gaagggtacc
241 tcccaccgac atgcctctcc attcttcac tccaggaaaa aaactgggtct gctttattga
301 caactgtcgt gattattctc accattgctg gaaatatact ggtcatcatg gcagtgtccc
361 tagaaaaaaa gctgcagaat gccaccaact atttctgat gtcacttgcc atagctgata
421 tgtgtctggg ttcccttgc atgcctgtgt ccatgttaac catcctgtat gggtagccgt
481 ggcctttgcc tagcaagctc tgtgcgatct ggattacct ggatgtgctc tttctacgg
541 catccatcat gcacctctgc gccatctccc tggaccgcta tgcgccatc cagaacccca
601 ttcaccacag ccgcttcaac tccagaacca aagccttctt gaaaatcatt gccgtgtgga
661 ccatatctgt aggtatatcc atgccaatcc cagtctttgg actacaggat gattcgaagg
721 tctttaagga ggggagctgc ctgcttgccg atgacaactt tttctcata ggctcttttg
781 tggcattttt catcccccta accatcatgg tgatcaccta ctccctgact atcaagtcac
841 ttcagaaaga agccaccttg tgtgtgagt acctcagcac tcgagccaaa ctaggcctct
901 tcagcttctt cctcagagt tctctgtcat cagaaaagct ctccaacgg tccatccaca
961 gagagccagg ctctacgca gcccgaagga cgtgcagtc catcagcaat gagcaaaagg
1021 cgaggaaggt gctgggcac gtgttcttc tgtttattgt aatgtggtgc ccattcttca
1081 tcaccaatat catggccgtc atctgcaaag aatcctgcaa tgaaaatgc atcggagccc
1141 tgctcaatgt gttgtcttg attggtatc tctcctcagc tgtcaatcca ctggtatata
1201 cgttgttcaa taaaacttat aggtccgct tctcaaggta cattcagtgt cagtacaagg
1261 aaaacagaaa gccactgcag ttaattttag tgaacactat accagcattg gcctacaagt

FIGURE 27

1321 ctagtcagct ccaggtggga cagaaaaaga actcacagga agatgctgag cagacagttg
1381 atgactgctc catggttaca ctggggaaac aacagtcgga agagaattgt acagacaata
1441 ttgaaaccgt gaatgaaaag gttagctgtg tgtgatgaac tggatgctat ggcaattgcc
1501 cagggcatgt gaacaagggt atacccatgt gtgtggggcg gggataagga ggctgcaaca
1561 aattag

FIGURE 27 - CONTINUED

Rat 5-HT_{2A} Cysteine → Glutamic Acid Mutant

MEILCEDNISLSSIPNSLMQLGDGPRLYHNDFNSRDANTSEASN
WTIDAENRTNLSCEGYLPPTCLSILHLQEKNEWSALLTTVVIIILTIAGNILVIMAVSLE
KKLQNAATNYFLMSLAIDMMLLGFLVMPVSMILTILYGYRWPLPSKLCAIWIYLDVLFST
ASIMHLCAISLDTRYVAIQNPPIHHSRFSNRTKAFLKIIAVWTISVGISMPIPVFGLQDD
SKVFKEGSCLLADDNFVLIGSFVAFFIPLTIMVITYFLTIKSLQKEATLCVSDLSTRA
KLASFSFLPQSSLSSEKLFORSIHREPGSYAGRRTMQSISNEQKA^EKVLGIVFFLFVV
MWCPPFITNIMAVICKESCNENVIGALLNVFVWIGYLSSAVNPLVYTLFNKTYRSAFS
RYIQCQYKENRKPLQLILVNTIPALAYKSSQLQVGQKKNSQEDAEQTVDDCSMVTLGK
QQSEENCTDNIETVNEKVSCV

FIGURE 28

Rat 5HT_{2A} Cysteine → Glutamic Acid Mutant

1 cccaggctat gaaccctag tctctccaca cttcatctgc tacaacttcc ggcttagaca
 61 tggaattct ttgtgaagac aatatctctc tgagctcaat tccaaactcc ttaatgcaat
 121 taggtgatgg cccgaggctc taccataatg acttcaactc cagagatgct aacacttcgg
 181 aagcatcgaa ctggacaatt gatgctgaaa acagaaccaa cctctcctgt gaaggggtacc
 241 tcccaccgac atgcctctcc attcttcac tccaggaaaa aaactgggtct gctttattga
 301 caactgtcgt gattattctc accattgctg gaaatatact ggtcatcatg gcagtgtccc
 361 tagaaaaaaa gctgcagaat gccaccaact atttctgat gtcacttccc atagctgata
 421 tgctgctggg ttctctgtc atgcctgtgt ccatgttaac catcctgtat ggggtaccgt
 481 ggcctttgcc tagcaagctc tgtgcgatct ggatttacct ggatgtgctc tttctacgg
 541 catccatcat gcacctctgc gccatctccc tggaccgcta tgcgccatc cagaacccca
 601 ttcaccacag ccgcttcaac tccagaacca aagccttctt gaaaatcatt gccgtgtgga
 661 ccatatctgt aggtatatcc atgccaatcc cagtctttgg actacaggat gattcgaagg
 721 tctttaagga ggggagctgc ctgcttgccg atgacaactt tgttctata ggctctttg
 781 tggcattttt catcccccta accatcatgg tgatcaccta ctctctgact atcaagtcac
 841 ttcagaaaga agccaccttg tgtgtgagtg acctcagcac tcgagccaaa ctagcctcct
 901 tcagcttctt cctcagagt tctctgtcat cagaaaagct cttccaacgg tccatccaca
 961 gagagccagg ctctacgca gcccgaagga ccatgcagtc catcagcaat gacaaaaagg
 1021 cggaaggt gctgggcac gtattcttc tttttgtt aatgtggtgc ccattcttca
 1081 tcaccaatat catggccgtc atctgcaaag aatcctgcaa tgaaaatgtc atcggagccc
 1141 tgctcaatgt gttgtctgg attggtatc tctcctcagc tgtcaatcca ctggtatata
 1201 cgttgttcaa taaaacttat aggtccgctt tctcaaggta cattcagtgt cagtacaagg
 1261 aaaacagaaa gccactgcag ttaattttag tgaacactat accagcattg gcctacaagt

Start C322E primer

End C322E primer

FIGURE 29

1321 ctagtcagct ccaggtggga cagaaaaaga actcacagga agatgctgag cagacagttg
1381 atgactgctc catggttaca ctggggaaac aacagtcgga agagaattgt acagacaata
1441 ttgaaaccgt gaatgaaaag gttagctgtg tctgatgaac tggatgctat ggcaattgcc
1501 cagggcatgt gaacaagggtt atacccatgt gtgtggggcg gggataagga ggctgcaaca
1561 aattag

FIGURE 29 - CONTINUED

Rat 5HT_{2A} Cysteine → Glutamic Acid Mutant with Restriction Site

1 cccaggctat gaacccttag tctctccaca cttcatctgc tacaacttcc ggcttagaca
61 tggaattct ttgtgaagac aatatctctc tgagctcaat tccaaactcc ttaatgcaat
121 taggtgatgg cccgaggctc taccataatg acttcaactc cagagatgct aacacttcgg
181 aagcatcgaa ctggacaatt gatgctgaaa acagaaccaa cctctcctgt gaaggggtacc
241 tcccaccgac atgcctctcc attcttcac tccaggaaaa aaactgggtct gctttattga
301 caactgtcgt gattattctc accattgctg gaaatatact ggtcatcatg gcagtgctcc
361 tagaaaaaaa gctgcagaat gccaccaact atttctgat gtcacttgcc atagctgata
421 tgtgctggg ttctctgtc atgcctgtgt ccatgttaac catcctgtat ggttaccgtt
481 ggcctttgcc tagcaagctc tgtgcgatct ggatttacct ggatgtgctc tttctacgg
541 catccatcat gcacctctgc gccatctccc tggaccgcta tctgccatc cagaacccca
601 ttcaccacag ccgcttcaac tccagaacca aagccttctt gaaaatcatt gccgtgtgga
661 ccatatctgt aggtatatcc atgccaatcc cagtctttgg actacaggat gattcgaagg
721 tctttaagga ggggagctgc ctgcttgccg atgacaactt ttttctcata ggctcttttg
781 tggcattttt catcccccta accatcatgg tgatcaccta cttctgact atcaagtcac
841 ttcagaaaga agccaccttg tgtgtgagtg acctcagcac tcgagccaaa ctgacctctt
901 tcagcttctt ccctcagagt tctctgtcat cagaaaaagt cttccaacgg tccatccaca
961 gagagccagg ctctacgca gcccgaagga cgtgcagtc catcagcaat gagcaaaagg
1021 cggaaggt actgggcatc gtgttcttc tttttgtt aatgtgtgc ccattcttca
1081 tcaccaatat catggccgtc atctgcaaag aatctgcaa tgaatatgc atcgagccc
1141 tgtcaatgt gttgtctgg attggttacc tctcctcagc tgtcaatcca ctggtatata
1201 cgttgttcaa taaaacttat aggtccgctt tctcaaggta cattcagtgt cagtacaagg
1261 aaaacagaaa gccactgcag ttaattttag tgaacactat accagcattg gcctacaagt

Start C322E primer
End C322E primer
↑ Mutation to create RsaI site

FIGURE 30

1321 ctagtcagct ccaggtggga cagaaaaaga actcacagga agatgctgag cagacagttg
1381 atgactgctc catggttaca ctggggaaac aacagtcgga agagaattgt acagacaata
1441 ttgaaaccgt gaatgaaaag gttagctgtg tgtgatgaac tggatgctat ggcaattgcc
1501 cagggcatgt gaacaagggtt atacccatgt gtgtggggcg gggataagga ggctgcaaca
1561 aattag

FIGURE 30 - CONTINUED

Rat 5-HT_{2c} Serine → Lysine Mutant

MVNLGNAVRSLLMHLIGLLVWQFDISISPVAIVTDTFNSSDGG

RLFQFPDGVQNWPAISIVVIIIIMTIGGNILVIMAVSMEKKLHNATNYFLMSLAIADML

VGLLVMPLSLLAILYDYVWPLPRYLCPVWISLDVLFSTASIMHLCAISLDRYVAIRNP

IEHSRFNSRTKAIMKIAIVWAISIGVSVPIPVIGLRDESKVFNNTTCVLNDPNFVLI

GSFVAFFIPLTIMVITYFLTIIYVLRRTLMLLRGHTEELANMSLNFLNCCCKKNGGE

EENAPNPNPDQKPRRKKKEKRPRGTMQAINNEKKA~~K~~KVLGIVFFVFLIMWCPFFITNI

LSVLCGKACNQKLMEKLLNVFVWIGYVCSGINPLVYTLENKIYRRAFSKYLRCDYKPD

KKPPVRQIPRVAATALSGRELNVNIYRHTNERVARKANDPEPGIEMQVENLELPVNPS

NVVSEISSV

FIGURE 31

Rat 5HT_{2c} Serine → Lysine Mutant

ORIGIN 23 bp upstream of HindIII site.

1 ggcgctctgg tgctcactga ggaagcttcc ttaggtgtac cgatcttaat gattgagccc
61 ttggagcagc aagattgtta atcttggttg ctctttggc ctgtctatcc cttaccttcc
121 tattacatat gaacttttct tcgttctgca catcgattgt cgtcggcgtc gtggagatcg
181 tcgtggtgct ccggtggtgg tcttcgtccg cttagaatag ttagttagt taggggcctt
241 caaagaagaa agaagaagcg attggcgcg agagatgctg gaggtgtcag ttctatgct
301 agagtagggg agtgaaacaa tccccagcca aacctttccg gggggcgag gttgccaca
361 ggaggtcgac ttgccggcgc tgccttcgc gccgagctcc ctccatcctt ctttcgctt
421 gctgagacgc aaggttgccg cgcgcacgct gacgagcgca ctgactgccg cgggctccgc
481 tgggcgattg cagccgagtc cgtttctcgt ctgctgccg ccgcgggcgc ctgcttggtc
541 ttctcccgg acgctagcgg gttgtcaact attacctgca agcataggcc aacgaacacc
601 ttctttcaa attaattgga atgaacaat tctgttaact tcctaattct cagtttgaa
661 ctctggttgc ttaagcctga agcaatcatg gtgaaccttg gcaacgcggt gcgctcgctc
721 ctgatgcacc taatcgccct attggtttgg caattcgata ttccataag tccagtagca
781 gctatagtaa ctgacacttt taattcctcc gatggtggac gcttgttca attccccgac
841 ggggtacaaa actgcccagc actttcaatc gtcgtgatta taatcatgac aatagggggc
901 aacattcttg ttatcatggc agtaagcatg gagaagaaac tgcacaatgc aaccaattac
961 ttcttaatgt ccctagccat tgctgatatg ctggtgggac tacttgcct gcccctgtcc
1021 ctgcttgcta ttctttatga ttatgtctgg cctttaccta gatattgtg ccccgctcgg
1081 attcactag atgtctatt ttcaactgcg tccatcatgc acctctgcgc catatcgctg
1141 gaccggtatg tagcaatagc taatcctatt gacgatagcc ggttcaattc gcgactaag
1201 gccatcatga agattgccat cgtttgggca atatcaatag gagtttcagt tccatccct

FIGURE 32

1261 gtgattggac tgagggacga aagcaaagtg ttctgaata acaccacgtg cgtgctcaat
1321 gaccccaact tcgttctcat cgggtccttc gtggcattct tcctccgtt gacgattatg
1381 gtgatcacct actcttaac gatctacgtc ctgcgccgtc aaactctgat gttacttga
1441 ggtcacaccg aggaggaact ggctaataatg agcctgaact ttctgaactg ctgctgcaag
1501 aagaatggtg gtgaggaaga gaacgctccg aaccctaatac cagatcagaa accacgtcga
1561 aagaagaaag aaaagcgtcc cagagggcacc atgcaagcta tcaacaacga aaagaaagct
1621 aaagaaagtcc ttggcattgt attctttgtg ttctgatca tgtgggtccc gttttcattc
1681 accaatatcc tgtcggttct ttgtgggaag gcctgtaacc aaaagctaata ggagaagctt
1741 ctcaatgtgt ttgtgtgat tggctatgtg tttcaggca tcaatcctct ggtgtacact
1801 ctctttaata aaatttaccg aagggctttc tctaaatatt tgcgctgcga ttataagcca
1861 gacaaaaagc ctctgttcg acagattcct agggttgctg ccactgcttt gtctgggagg
1921 gagctcaatg ttaacattta tcggcatacc aatgaacgtg tggctaggaa agctaattgac
1981 cctgagcctg gcatagagat gcagggtggag aacttagagc tgccagtcaa cccctctaata
2041 gtggtcagcg agaggattag tagtgtgtaa gcgaagagca ggcagactt cctacaggaa
2101 agttcctgta ggaaagtcct cccaccccc cgtgattttc ctgtgaatca taactaatgt
2161 aaatattgct gtgtgacaag acagtgtttt tataaatagc ttgcaaccc tgtactttac
2221 atcatgcgtt aatagtgaga ttcggg

FIGURE 32 - CONTINUED

Rat 5HT_{2c} Serine → Lysine Mutant with Restriction Site

ORIGIN 23 bp upstream of HindIII site.

1 ggcgctctgg tgctcactga ggaagcttcc ttaggtgtac cgatcttaat gattgagccc
61 ttggagcagc aagattgtta atcttggtg ctccttggc ctgtctatcc ctaccttcc
121 tattacatat gaacttttct tcgttctgca catcgattgt cgtcggcgtc gtggagatcg
181 tcgtggtgct ccggtggtgg tcttcgtccg cttagaatag ttagttagt taggggcctt
241 caaagaagaa agaagaagcg attggcgcg agagatgctg gaggtgtcag ttctatgct
301 agagtagggt agtgaaacaa tcccagcca aacctttccg gggggcgag gttgccaca
361 ggaggtcgac ttgccggcgc tgctctcgc gccgagctcc ctccatcctt ctttcgctt
421 gctgagacgc aaggttgccg cgcgcacgt gagcagcgca ctgactgccg cgggctccg
481 tgggcgattg cagccgagtc cgtttctgt ctagctgccg ccgcggcgac ctgcctggc
541 ttctcccgg acgctagcgg gttgtcaact attacctgca agcataggcc aacgaacacc
601 ttctttcaa attaattgga atgaaacaat tctgttaact tcctaattct cagtttgaa
661 ctctggttgc ttaagcctga agcaatcatg gtgaaccttg gcaacgcggt gcgctcgtc
721 ctgatgcacc taatcggcct attggttgg caattcgata ttccataag tccagtagca
781 gctatagtaa ctgacacttt taattcctcc gatggtggac gcttgttca attcccggac
841 ggggtacaaa actggccagc actttcaatc gtcgtgatta taatcatgac aatagggggc
901 aacattcttg ttatcatggc agtaagcatg gagaagaaac tgcacaatgc aaccaattac
961 ttcttaatgt ccctagccat tgctgatatg ctggtgggac tactgtcat gccctgtcc
1021 ctgcttgcta ttctttatga ttatgtctgg cctttaccta gatatttgtg ccccgctcgg
1081 atttcactag atgtgctatt ttcaactgcg tccatcatgc acctctgcgc catatcgctg
1141 gaccggtatg tagcaatacg taatcctatt gagcatagcc ggttcaattc gcggactaag
1201 gccatcatga agattgccat cgttgggca atatcaatag gagtttcagt tcctatccct

FIGURE 33

1261 gtgattggac tgagggacga aagcaaagtg ttctgaata acaccacgtg cgtgctcaat
1321 gaccccaact tcgttctcat cgggtccttc gtggcattct tcatcccggt gacgattatg
1381 gtgatcacct acttcttaac gatctacgtc ctgcgccgtc aaactctgat gttacttcga
1441 ggtcacaccg aggaggaact ggctaataatg agcctgaact ttctgaactg ctgctgcaag
1501 aagaatggtg gtgaggaaga gaacgctccg aaccctaatac cagatcagaa accacgtcga
1561 aagaagaaag aaaagcgtcc cagaggcacc atgcaagcta tcaacaacga aaagaagct
1621 aaagaaagtac ttggcattgt attctttgtg ttctgatca tgtggtgccc gtttttcac
1681 accaatatcc tgcggttct ttgtgggaag gcctgtaacc aaaagctaata ggagaagctt
1741 ctcaatgtgt ttgtgtggat tggctatgtg ttctcaggca tcaatcctct ggtgtacact
1801 ctctttaata aaatttaccg aagggctttc tctaaatatt tgcgctgcga ttataagcca
1861 gacaaaaagc ctctgttcg acagattcct agggttgctg ccactgcttt gtctgggagg
1921 gagctcaatg ttaacattta tcggcataacc aatgaacgtg tggctaggaa agctaatac
1981 cctgagcctg gcatagagat gcaggtggag aacttagagc tgccagtcaa cccctctaata
2041 gtggtcagcg agaggattag tagtgtgtaa gcgaagagca ggcgagactt cctacaggaa
2101 agttcctgta ggaaagtcct cccaccccc cgtagtttc ctgtgaatca taactaatgt
2161 aaatattgct gtgtgacaag acagtgtttt tataaatagc ttgcaaccc tgtactttac
2221 atcatgcgtt aatagtgaga ttcggg

FIGURE 33 - CONTINUED

Rat 5-HT_{2c} Serine → Phenylalanine Mutant

MVNLGNAVRSLLMHLIGLLVWQFDISISPVA AIVTDTFNSSDGG
RLFQFPDGVQNWPA LSIVV IIMTIGGNILVIMAVSMEKKLHNATNYFLMSLA IADML
VGLLVMPLSLLAILYDYVWPLPRYLCPVWISLDVLFSTASIMHLCAISLD RYVAIRNP
IEHSRFNSRTKAIMKIAIVWAISIGVSVPIPVIGLRDESKV FVNNTTCVLNDPNFVLI
GSFVAFFIPLTIMVITYFLT IYVLR RQTLMLLRGHTEEELANMSLNFLNCCCKKNGGE
EENAPNPNPDQKPRRKKKEKRPRGTMQAINNEKKA FKVLGIVFFVFLIMWCPFFITNI
LSVLCGKACNQKLMEKLLNVFVWIGYVCSGINPLVYT LFNKIYRRAFSKYLRC DYKPD
KKPPVRQIPRVAATALSGRELNVNIYRHTNERVARKANDPEPGIEMQVENLELPVNPS
NVVSERISSV

FIGURE 34

Rat 5HT_{2c} Serine → Phenylalanine Mutant

ORIGIN 23 bp upstream of HindIII site.

1 ggcgctctgg tgctcactga ggaagcttcc ttaggtgtac cgatcttaat gattgagccc
61 ttggagcagc aagattgtta atcttggttg ctctttggc ctgtctatcc cttaccttcc
121 tattacatat gaacttttct tcgttctgca catcgattgt cgtcggcgctc gtggagatcg
181 tcgtggtgct ccggtggtgg tcttcgtccg cttagaatag ttagttagt taggggcctt
241 caaagaagaa agaagaagcg attggcgcgg agagatgctg gaggtgtcag tttctatgct
301 agagtagggt agtgaaacaa tccccagcca aacctttccg gggggcgag gttgccaca
361 ggaggtcgac ttgccggcgc tgccttcgc gccgagctcc ctccatcctt cttccgtct
421 gctgagacgc aaggttgccg cgcgacgct gagcagcgca ctgactgccg cgggctccgc
481 tgggcgattg cagccgagtc cgtttctcgt ctgctgccg ccgcggcgac ctgcctggtc
541 ttctcccg acgctagcgg gttgtcaact attacctgca agcataggcc aacgaacacc
601 ttctttcaa attaattgga atgaacaat tctgttaact tctaattct cagtttgaaa
661 ctctggttgc ttaagcctga agcaatcatg gtgaaccttg gcaacgggt gcgctcctc
721 ctgatgcacc taatcggcct attggttgg caattcgata ttccataag tccagtagca
781 gctatagtaa ctgacacttt taattcctcc gatggtagac gcttattca attccggac
841 ggggtacaaa actggccagc acttcaatc gtcgtgatta taatcatgac aatagggggc
901 aacattcttg ttatcatggc agtaagcatg gagaagaaac tgcacaatgc aaccaattac
961 ttcttaatgt ccctagccat tctgatatg ctggtgggac tactgtcat gcccctgtcc
1021 ctgcttgcta ttctttatga ttatgtctgg ctttaccta gatatttgt ccccgctgg
1081 attcactag atgtgctatt ttcaactgcg tccatcatgc acctctgcgc catatcgctg
1141 gaccggtatg tagcaatagc taatcctatt gagcatagcc ggttcaattc gcggactaag
1201 gcatcatga agattgccat cgtttgggca atatcaatag gagtttcagt tctatccct

FIGURE 35

1261 gtgattggac tgagggacga aagcaaagtg ttctgaata acaccacgtg cgtgctcaat
1321 gaccccaact tcgttctcat cgggtccttc gtggcattct tcatcccggt gacgattatg
1381 gtgatcacct acttcttaac gatctacgtc ctgcgccgtc aaactctgat gttacttcga
1441 ggtcacaccg aggaggaact ggctaatacg agcctgaact ttctgaactg ctgctgcaag
1501 aagaatggtg gtgaggaaga gaacgctccg aaccctaata cagatcagaa accacgtcga
1561 aagaagaaag aaaagcgtcc cagaggcacc atgcaagcta tcaacaacga aaagaaagct
1621 ttcCaaagtcc ttggcattgt attctttgtg ttctgatca tgtggtgccc gttttcacc
1681 accaatatcc tctcggttct ttgtgggaag gcctgtaacc aaaagctaata ggagaagctt
1741 ctcaatgtgt ttgtgtggt ttgctatgtg ttttcaggca tcaatcctct ggtgtacact
1801 ctctttaata aaatttaccg aagggtcttc tctaaatatt tgcgctgcga ttataagcca
1861 gacaaaaagc ctctgttcg acagattcct agggttcctg ccactgcttt gtctgggagg
1921 gagctcaatg ttaacattta tcggcatacc aatgaacgtg tggctaggaa agctaatac
1981 cctgagcctg gcatagagat gcaggtggag aacttagagc tgccagtcaa cccctctaata
2041 gtggtcagcg agaggattag tagtgtgtaa gcgaagagca ggcgagactt cctacaggaa
2101 agttcctgta ggaaagtcct cccaccccc cgtgattttc ctgtgaatca taactaatgt
2161 aatattgct gtgtgacaag acagtgtttt tataaatagc ttgcaaccc tgtactttac
2221 atcatgcgtt aatagtgaga ttcggg

FIGURE 35 - CONTINUED

Rat 5HT_{2c} 312Serine → Phenylalanine Mutant with Restriction Site

ORIGIN 23 bp upstream of HindIII site.

1 ggcgctctgg tgctcactga ggaagcttcc ttaggtgtac cgatcttaat gattgagccc
61 ttggagcagc aagattgtta atcttggtg ctctttggc ctgtctatcc ctaccttcc
121 tattacatat gaacttttct tcgttctgca catcgattgt cgtcggcgctc gtggagatcg
181 tcgtggtgct ccggtggtgg tcttcgtccg cttagaatag tgtagttagt taggggcctt
241 caaagaagaa agaagaagcg attggcgcg agagatgctg gaggtgtcag tttctatgct
301 agagtagggg agtgaaacaa tcccagcca aacctttccg gggggcgag gttgccaca
361 ggaggtcgac ttgccggcg tgctcttcgc gccgagctcc ctccatcctt ctttccgtct
421 gctgagacgc aaggttgcg cgcgacgct gagcagcgca ctgactgccg cgggctccgc
481 tgggcgattg cagccgagtc cgtttctgt ctgactgccg ccgcggcgac ctgcctggtc
541 ttctccccg acgctagcgg gttgtcaact attacctgca agcataggcc aacgaacacc
601 ttctttcaa attaattgga atgaaacaat tctgttaact tcctaattct cagtttgaaa
661 ctctggttgc ttaagcctga agcaatcatg gtgaaccttg gcaacgcggt gcctcgcctc
721 ctgatgcacc taatcgccct attggtttgg caattcgata ttccataag tccagtagca
781 gctatagtaa ctgacacttt taattcctcc gatggtggac gcttgttca attccccgac
841 gggtacaaa actggccagc actttcaatc gtcgtgatta taatcatgac aatagggggc
901 aacattcttg ttatcatggc agtaagcatg gagaagaaac tgcacaatgc aaccaattac
961 ttcttaattg ccctagccat tgctgatatg ctggtgggac tacttgcctat gcccctgtcc
1021 ctgcttgcta ttctttatga ttatgtctgg cctttaccta gatatttgtg ccccgtctgg
1081 atttcactag atgtctatt ttcaactgcg tccatcatgc acctctggc catatcgctg
1141 gaccggtatg tagcaatagc taatcctatt gagcatagcc ggttcaattc ggggactaag
1201 gccatcatga agattgccat cgtttgggca atatcaatag gagtttcagt tcctatccct

FIGURE 36

1261 gtgattggac tgagggacga aagcaaagtg ttcgtgaata acaccacgtg cgtgctcaat
1321 gaccccaact tcgtttcat cgggtccttc gtggcattct tcatcccggt gacgattatg
1381 gtgatcacct acttctaac gatctacgtc ctgcgccgtc aaactctgat gttacttcga
1441 ggtcacaccg aggaggaact ggctaatacg agcctgaact ttctgaactg ctgctgcaag
1501 aagaatggtg gtgaggaaga gaacgctccg aaccctaatac cagatcagaa accacgtcga
1561 aagaagaaag aaaagcgtcc cagaggcacc atgcaagcta tcaacaacga aaagaaagct
1621 ttc[↑]aaagtac ttggcattgt attctttgtg ttctgatca tgtggtgccc gttttcattc
1681 accaatatcc tgtcgtttct ttgtgggaag gcctgtaacc aaaagctaata ggagaagctt
1741 ctcaatgtgt ttgtgtgat tggctatgtg ttttcaggca tcaatcctct ggtgtacact
1801 ctctttaata aaatttaccg aagggccttc tctaaatatt tgcgctgcga ttataagcca
1861 gacaaaaagc ctctgttcg acagattcct agggttgctg ccactgcttt gtctgggagg
1921 gagctcaatg ttaacattta tcggcatacc aatgaacgtg tggctaggaa agctaattgac
1981 cctgagcctg gcatagagat gcaggtggag aacttagagc tccagatcaa cccctctaata
2041 gtggtcagcg agaggattag tagtgtgtaa gcgaagagca gcgcagactt cctacaggaa
2101 agttcctgta ggaaagtcct cccaccccc cgtgattttc ctgtgaatca taactaatgt
2161 aatattgct gtgtgacaag acagtgtttt tataaatagc ttgcaaccc tgtactttac
2221 atcatgcgtt aatagtgaga ttcggg

FIGURE 36 - CONTINUED

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/03991

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : C07K 14/705; C12N 15/10, 15/12
US CL : 435/69.1, 172.3; 530/350, 536/23.5

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/69.1, 172.3; 530/350, 536/23.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Elken et al. Application of natural and amplification created restriction sites for the diagnosis of PKU mutations. Nucleic Acids Research. July 1991. Vol. 19, No. 7. pages 1427 to 1430, see entire document.	14, 15
Y	Kao et al. Site-directed mutagenesis of a single residue changes the binding properties of the serotonin 5-HT2 receptor from a human to a rat pharmacology. FEBS Letts. August 1992, Vol. 307, No. 3. pages 324-328, see in particular Figures 1 and 2.	1-13, 16-24

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 14 MAY 1998	Date of mailing of the international search report 23 JUN 1998
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer JOHN D. ULM Telephone No. (703) 308-0196

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US98/03991

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Boone et al. Mutations that alter the third cytoplasmic loop of the a-factor receptor lead to a constitutive and hypersensitive phenotype. Proc. Natl. Acad. Sci. November 1993. Vol. 90. pages 9921-9925. see especially Figure 2.	1-13, 16-24
Y	Parma et al. Somatic mutations in the thyrotropin receptor gene cause hyperfunctioning thyroid adenomas. Nature, 14 October 1993. Vol. 365. pages 649-651. especially Figure 2.	1-13, 16-24
Y	Shenker et al. A constitutively activating mutation of the luteinizing hormone receptor in familial male precocious puberty. Nature, 14 October 1993. Vol. 365. pages 652-654. especially Figure 1c.	1-13, 16-24
Y	Cohen et al. Constitutive Activation of Opsin, Influence of Charge at Position 134 and Sizre at Position 296. Biochemistry. December 1993. Vol. 32. No. 23. pages 6111-6115, see entire document.	1-13, 16-24
Y	Samama et al. A Mutation-induced Activated State of the beta2-adrenergic receptor. Journal of Biological Chemistry. 05 March 1993. Vol. 268. No. 7. pages 4625-4636. especially Figure 1.	1-13, 16-24
Y	Kjelsberg et al. Conservative Activation of the alpha1B-Adrenergic Receptor by All Amino Acid Substitutions at a Single Site. Journal of Biological Chemistry. 25 January 1992. Vol. 267. No. 3. pages 1430-1433. especially Figure 1.	1-13, 16-24
Y	Ren et al. Constitutively Active Mutans of the alpha2-Adrenergic Receptor. Journal of Biological Chemistry. 05 August 1993. Vol. 268. No. 22. pages 16483-16487. especially Figure 1.	1-13, 16-24
Y	Bluml et al. Functional Role of a Cytoplasmic Aromatic Amino Acid in Muscarinic Receptor-mediated Activation of Phospholipase C. Journal of Biological Chemistry. 15 April 1994. Vol. 269. No.15. pages 11537-11541. especially Figure 1.	1-13, 16-24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/03991

B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

APS, STN/MEDLINE

search terms: polymerase chain reaction, site directed mutagenesis, cleavage site#, constitutiv?, activ?, receptor#, G protein#

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claims 1-13, 16-22, drawn to a nucleic acid encoding a constitutively active receptor and the protein encoded thereby.

Group II, claims 14-15, drawn to a method of site directed mutagenesis.

Group III, claims 23-24, drawn to a transgenic animal.

The inventions listed as Groups I, II and III do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: Inventions I and III are materially different inventions which lack a common utility based upon a common special technical feature that is disclosed as responsible for that utility and which is lacking from the prior art. Invention II is unrelated to inventions I and III because it is a method which performs a different function, operates upon a different principal and achieves a different result. Accordingly, the claims are not so linked by a special technical feature within the meaning of PCT Rule 13.2 so as to form a single inventive concept.